School of Physiotherapy and Exercise Science

Breast size and upper back pain

Linda Spencer

This thesis is presented for the degree of

Doctor of Philosophy

of

Curtin University

October 2019

Declaration

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made.

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RDHS-267-15.

I warrant that I have obtained, where necessary, permission from the copyright owners to use any third-party copyright material reproduced in the thesis and to use the published work I have authored in which the copyright is held by another party.

Linda Spencer

October 2019

Abstract

Upper back pain (UBP) is a term used to describe pain in the region of the thoracic spine. The prevalence of UBP is high amongst mature-aged women. Unlike lower back pain and neck pain, the aetiology of UBP in healthy mature-aged women has not been examined widely and risk factors for the condition remain relatively undetermined. Identifying risk factors for musculoskeletal conditions such as UBP is consistent with a national strategic priority to promote the healthy ageing of women in Australia, and is an important step in reducing the substantial health and economic burdens attached to chronic musculoskeletal back pain conditions.

Increased breast size is a possible risk factor for UBP that has been acknowledged in research of women seeking reduction mammoplasty and in women more generally. The long-standing theory that links increased breast size to UBP via biomechanical mechanisms has had limited objective substantiation and the physical basis for UBP in women with larger breasts remains uncertain. Mature-aged women, who are likely to undergo physical changes in their upper back and breasts with age, are an important population in which to consider the relationship between breast size and UBP. Quantitatively investigating the importance of breast size relative to other potential risk factors for UBP should benefit the health and psychological wellbeing of mature-aged women by identifying modifiable associated factors that can be targeted clinically.

The overall aim of this doctoral research project was to investigate the relationship between breast size and UBP in mature-aged women. Six research questions, addressed sequentially in the chapters of this thesis, directed research activities involving two samples of women. For cross-sectional studies, self-report data were collected from a sample of women aged ≥40 years (community-based sample). Objective measures were collected from a subset of 119 of these women, 61 with UBP and 58 without UBP, who were all postmenopausal (postmenopausal subset). A repeated measures methodology was used with the second sample that included adult women seeking reduction mammoplasty (surgical sample, n=11).

Self-report data on UBP and aspects of health and psychological wellbeing were collected from all participants using a survey that incorporated specifically-designed questions (participant information questionnaire) and standardised questionnaires. Upper back pain was assessed as present or not (within the previous month) and as a pain severity score (Numerical Rating Scale, NRS). Information gathered from all participants included: participant characteristics (age, height, weight), menopausal status (pre/peri/post-

menopausal), employment status (employed/nil employment), breast size (bra size), bra fitting habits, bra fit satisfaction, breast embarrassment, desire to change breasts, breast satisfaction (BREAST-Q), physical activity levels (Human Activity Profile), health-related quality of life (HRQoL)(Medical Outcomes Study Short-Form 36 Health Survey (SF-36) and BREAST-Q), and body satisfaction (NRS). Further information gathered from the surgical sample were: neck pain disability (Neck Disability Index), shoulder pain (NRS), pain chronicity (Orebro Musculoskeletal Pain Screening Questionnaire), and surgery outcome satisfaction (BREAST-Q).

Objective measures of physical characteristics were completed on one occasion for participants in the postmenopausal subset, and preoperatively and at 3, 6 and 12-months postoperatively for participants in the surgical sample. Physical characteristics that were assessed included: height, weight, body mass index (BMI), bone mineral density (BMD) (dual energy X-ray absorptiometry, DXA), body composition (DXA), breast size (measured bra size), breast ptosis (tape measure), breast splay (tape measure), bra fit (professional criteria), upper back extensor muscle endurance (isometric chest raise test), upper back mobility (photogrammetry), thoracic kyphosis (radiography), thoracic spine morphology (including intervertebral osteoarthritis, vertebral fractures) (radiography), posture (including head, upper back and shoulder posture) (photogrammetry), and upper back musculoskeletal tissue sensitivity (digital algometry).

Research activities were preceded by preliminary work to test the practicability and reliability of selected methods. Two studies which recruited a separate sample of women aged ≥40 years (pilot sample, n=20) were completed as part of this preliminary work. The first was a repeated measures study of photographic methods and digital algometry to determine the reliability of these techniques for measuring posture, upper back mobility, and upper back musculoskeletal tissue sensitivity in mature-aged women (Chapter 3). It determined that measurements of posture and upper back mobility could be made reliably using photographic methods and that tissue sensitivity could be measured reliably using digital algometry. It was also established that posture was more reliably measured with participants in standing. The second study (Chapter 4) was a repeated measures study of breast size that compared three methods (anthropometric method, self-reported bra size, and measured bra size) for determining breast size. It established that an ordinal breast size score (BSS) was a reliable measure of breast size via self-report and objective means in mature-aged women. The methods tested in both studies were practicable and well-tolerated by participants.

The methods of the main project were also informed by a validity study (Chapter 5) that compared radiological and non-radiological methods for assessing thoracic kyphosis in postmenopausal women. Using data collected from participants in the postmenopausal subset who had radiographic measures completed (n=117), this study established that the Flexicurve ruler was not an adequate substitute for radiographic methods in measuring the magnitude of thoracic kyphosis in postmenopausal women.

The main project began with an exploratory approach to determine if aspects of health and psychological wellbeing (UBP, HRQoL, breast and body satisfaction, and physical activity) were associated with breast size in mature-aged women (Chapter 6). Self-report data from the community-based sample were analysed. Age, menopausal status and BMI were examined as covariates. The data of 269 women (aged 40-85 years) whose bra band sizes ranged from 8 to 26 and bra cup sizes from A to HH (BSS: 2-16), indicated that increments in breast size (breast size score), contributed to a 13% increase in the likelihood of UBP. In addition, aspects of psychological wellbeing that were negatively associated with larger breast sizes included: breast-related physical wellbeing ($R^2=0.043$, $p<0.001$), body satisfaction ($R^2=0.024$, $p=0.002$), and breast satisfaction ($R^2=0.065$, $p<0.001$). This suggested that the burden of larger breasts in mature-aged women is reflected in several aspects of health and psychological wellbeing and that UBP could be a measurable part of this.

The project then focused on factors associated with the presence and severity of UBP. In the first instance, the self-report data of the community-based sample were re-examined to determine if there were aspects of health and psychological wellbeing associated with UBP that were independent of breast size (Chapter 7). The presence and severity of UBP were examined against the self-report variables of height, weight, BMI, menopausal status, employment status, physical activity levels, HRQoL, body satisfaction, and breast satisfaction. Multivariable models adjusted for age and breast size, determined self-report characteristics independently associated with increasing the likelihood (presence) (logistic regression model) and severity (Tobit regression model) of UBP. Breast satisfaction and SF-36 physical component summary (PCS) scores, were negatively associated with both the presence and severity of UBP, and were identified as two characteristics important to the experience of UBP. The relationships between UBP and these characteristics highlighted that how a woman feels about her breasts and health, irrespective of her breast size, could be important considerations when exploring the reasons for her UBP.

In the second approach to examining factors associated with UBP, breast size was examined objectively alongside a large collection of other physical characteristics in the

postmenopausal subset (n=119) (Chapter 8). An equal representation of participants with and without UBP (n=61 and n=58 respectively) in this sample, achieved using consecutive sampling, allowed physical characteristics to be compared between these participant groups. The presence and severity of UBP were examined against participants' height, weight, BMI, BMD, body composition, breast size, breast ptosis, bra fit, upper back extensor muscle endurance, upper back mobility, thoracic kyphosis, thoracic spine morphology, and posture. Very few physical characteristics differed between participants with UBP and those without. Multivariable models, adjusted for age, for both the presence (logistic regression) and severity (Tobit regression) of UBP identified the importance of upper back extensor muscle endurance over and above other physical characteristics. Better muscle endurance was associated with a lower odds (OR: 0.46, 95%CI: 0.28 to 0.75) and severity (OR:-0.91, 95%CI: -1.35 to -0.48) of UBP. Breast size was a less conspicuous associated risk factor for UBP when considered amongst other physical characteristics.

The notion of a physical basis for the relationship between breast size and UBP was explored by first examining the association between physical characteristics and breast size in the postmenopausal subset (Chapter 9). Physical characteristics that were considered to be relevant to explaining the relationship between breast size and UBP were assessed against breast size using linear regression. The physical characteristics including: upper back extensor muscle endurance, upper back mobility, thoracic kyphosis and posture were dependent variables in models, adjusted for age, and analysed against breast size as the independent variable. In addition, although not as outcomes, height, lean mass, fat mass, breast ptosis and breast splay were examined in relation to breast size. Participants with larger breasts had significantly more body fat, greater breast ptosis and greater breast splay. Participants with larger breast size also had significantly less upper back extensor muscle endurance (OR: -5.91, 95%CI: -9.98 to -1.85), a more forward head posture (OR: -0.50, 95%CI: -0.86 to -0.13), a more rounded upper back posture (OR: 0.45, 95%CI: 0.14 to 0.76) and a more protracted shoulder posture (OR: -0.67, 95%CI: -1.19 to -0.16). Breast size explained a significant but small (<10%) proportion of the variance in these physical characteristics. By cross-examining these results with those already generated, upper back extensor muscle endurance was identified as a physical characteristic with relevant links to increasing breast size and UBP. This suggests that upper back extensor muscle endurance may contribute to explaining the link between breast size and UBP in some participants.

In two novel approaches, the project also investigated breast size in relation to prevalent vertebral fractures and upper back musculoskeletal tissue sensitivity. The first of these approaches was a study that used the objective measures of breast size, body composition,

upper back extensor muscle endurance, thoracic kyphosis, and vertebral fractures from participants in the postmenopausal subset who had radiographic measures completed (n=117) (Chapter 10). Participants with ≥ 1 prevalent vertebral fracture (n=17) were initially compared to those without vertebral fracture (n=100). Participants with vertebral fracture had significantly larger breasts, less upper back extensor muscle endurance and greater thoracic kyphosis. There were no between group differences in BMD or UBP severity. In a multivariable model adjusted for BMD, breast size (OR: 1.85, 95%CI: 1.10 to 3.10) and thoracic kyphosis (OR: 2.04, 95%CI: 112-3.70) were associated with a significantly increased odds of vertebral fracture. Breast size had a significant but weak relationship with vertebral fracture ($R^2 = 0.10$) which was independent of BMD and unrelated to thoracic kyphosis. Further prospective work to determine the temporal relationship between breast size, thoracic kyphosis and fracture risk could help to identify if vertebral fractures are a clinical consequence of larger breasts.

The second study examined breast size and UBP in relation to musculoskeletal sensitivity in participants in the postmenopausal subset (n=119) (Chapter 11). The pressure pain thresholds (PPTs) of selected upper back musculoskeletal tissues, theoretically linked to the postural adaptations to larger breasts, were investigated. Pressure pain threshold was measured over the spinous processes of T2, T4, T6, T8, T10 and T12, and on the non-dominant side over pectoralis major, levator scapulae, sternocleidomastoid, and upper, middle and lower trapezius muscles. Linear mixed models with random subject effects were used to evaluate differences in sensitivity at each anatomical site between participants grouped by breast size (small (BSS<7), large (BSS≥7)) and UBP (nil-mild (NRS<4), moderate-severe (NRS≥4)). For most sites the differences in sensitivity between UBP groups were highly significant (p<0.002) with significantly lower PPTs (MD: 74.6-151.1kPa) recorded for participants with moderate-severe upper back pain. There were no differences in sensitivity between breast size groups. The findings of this study show that increased upper back musculoskeletal sensitivity is related to UBP but not to breast size. This suggests the strain on upper back musculoskeletal tissues due to large breasts is unlikely to be a physiological basis for upper back pain in women.

In the final part of the project, characteristics that change alongside UBP were examined in participants of the surgical sample (Chapter 12). Using the largest collection of characteristics to have been examined longitudinally before and after reduction mammoplasty, this work identified trends in the nature, rate and clinical relevance of improvements that occur. Eleven women provided complete datasets which included all self-report and physical measures over four time points. Upper back pain was reported by 91% of

participants preoperatively. Following breast reductions with a mean resection weight of 965g, the severity of UBP improved by 80% at 6-months post-surgery. In addition there were significant improvements in severities of neck and shoulder pain. Characteristics that changed significantly by clinically meaningful amounts were largely self-report in nature, were maintained up to 12-months postoperatively, and were independent of breast resected weight. Breast satisfaction (214%) and breast-related psychosocial wellbeing (97%) were characteristics showing the greatest percentage improvement. Upper back extensor muscle endurance improved to a clinically meaningful level but the change was not statistically significant. Head posture improved significantly but by amounts that were probably of little clinical relevance. This prospective work suggests that improvements in UBP conferred by reduction mammoplasty were most clearly reflected in self-report accounts of women and less clearly by changes in their physical characteristics up to 12 months post-surgery.

The cross-sectional research in this doctoral research project highlights the multidimensional and multifactorial nature of UBP. It provides evidence that breast size may be considered an associated risk factor for UBP in some mature-aged women but that perceptions of breast satisfaction and physical health could also be an important expression of this relationship. Relative to other physical characteristics in postmenopausal women specifically, increased breast size has shown a weaker relationship with the presence and severity of UBP than expected. High levels of upper back extensor muscle endurance, that reduce the likelihood and severity of UBP, is the only modifiable physical characteristic examined, that could be worth targeting clinically. In postmenopausal women with larger breasts improving upper back extensor muscle endurance could provide a reduction in the likelihood and severity of UBP.

Increased breast size is identified to be associated with prevalent vertebral fractures. Although there is a need for further studies to investigate UBP as an outcome related to this, vertebral fractures are a potential clinical outcome of larger breasts that need further consideration in future biomechanical theories linking breast size to UBP. Increased breast size is not related to greater upper back musculoskeletal tissue sensitivity, which provides further perspective on existing biomechanical theories linking larger breasts to skeletal and muscular strain.

A comparison of the prospective work of this project with the cross-sectional findings, triangulates the understanding of the relationship between breast size and UBP. Breast satisfaction and SF-36 PCS scores are confirmed as important influences on the experience of UBP. These are characteristics negatively associated with increasing breast size that also increase the likelihood and severity of UBP. Improvements in breast satisfaction and SF-36

PCS scores that stand out over and above other characteristics relative to UBP following reduction mammoplasty, emphasise their importance to UBP in women with larger breasts.

The physical characteristics that have been examined in this project have a less certain role in explaining UBP. There are few physical characteristics related to UBP that influence its severity substantially. This may explain why it has been difficult to clearly identify physical characteristics that improve significantly alongside UBP in women undergoing reduction mammoplasty. Greater levels of upper back extensor muscle endurance could have a small protective role against the likelihood and severity of UBP, particularly in women with larger breasts, but as a characteristic involved in the explaining the link between increased breast size and UBP, it needs further investigation.

Acknowledgements

My parents, Hazel and Colin Spencer, for the perseverance, determination and work ethic that you both have instilled in me which has undoubtedly helped me to complete this academic mission.

My special big brothers, Stephen and Alan Spencer, for the confidence and toughness that you both made sure I had ingrained ready to take on such an ambitious challenge.

My family, friends, work colleagues and patients for their encouragement and good wishes along the journey.

Iain, for being by my side as I put my heart and mind into this work.

This thesis is dedicated to those who inspired it and to those who participated. If it were not for the numerous mature-aged women presenting clinically with upper back pain who considered their breast size to be relevant to their symptoms, this PhD journey would never have started. And, if were not for those who generously gave their time to participate, this PhD journey would not have been completed. The work of this thesis brings us a small step closer to understanding the relationship between breast size and upper back pain and I thank you for helping to make that happen.

List of publications

Spencer L, Fary R, McKenna L, Ho R, Briffa K. Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods. Osteoporos Int. 2019; 30(10): 2009-2018. DOI: 10.1007/s00198-019-05023-5.

Spencer L, McKenna L, Fary R, Ho R, Jacques A, Briffa K. Upper back pain in postmenopausal women and associated physical characteristics. PLoS One. 2019; DOI:10.1371/journal.pone.0220452.

Spencer L, Fary R, McKenna, L, Lalor J, Jacques A, Briffa K. The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women. Women's Health. 2020; 16:1-11. DOI: 10.1177/1745506520918335.

Spencer L, McKenna L, Fary R, Ho R, Briffa, K. Is breast size related to prevalent vertebral fracture? A cross-sectional study. J Bone Miner Res Plus. 2020; DOI: 10.1002/jbm4.10371.

Conference podium presentations

Spencer L, McKenna L, Fary R, Ho R, Briffa K. Clinical assessment of thoracic kyphosis using Flexicurve: measurement error increases with age and angle. World Confederation for Physical Therapy Congress 2019, Geneva, Switzerland, PLR5-1917.

Spencer L, Fary R, McKenna, L, Lalor J, Jacques A, Briffa K. Do women with UBP differ from those without? Relationship between age, breast size, physical activity, wellbeing, body satisfaction and upper back pain. World Confederation for Physical Therapy Congress 2019, Geneva, Switzerland, PL-1719.

Conference poster presentations

Spencer L, McKenna L, Fary R, Ho R, Briffa, K. Thoracic kyphosis measurement in postmenopausal women. An examination of the Flexicurve method in comparison to radiological methods. The International Osteoporosis Foundation Regional – 7th Asia-Pacific Osteoporosis Conference 2018, Sydney, Australia, PO78.

Spencer L, McKenna L, Fary R, Ho R, Briffa K. Is breast size related to thoracic vertebral fracture risk? The International Osteoporosis Foundation Regional – 7th Asia-Pacific Osteoporosis Conference 2018, Sydney, Australia, PO75.

Spencer L, McKenna L, Fary R, Ho R, Briffa K. Physical characteristics associated with upper back pain in postmenopausal women. What's age and breast size got to do with it? World Confederation for Physical Therapy Congress 2019, Geneva, Switzerland, PO-15-SAT2.

Spencer L, McKenna L, Fary R, Ho, R, Briffa, K. What you should know before treating upper back pain in postmenopausal women with large breasts. World Confederation for Physical Therapy Congress 2019, Geneva, Switzerland, PO-F-15-SUN1.

Spencer L, Fary R, McKenna, L, Lalor J, Jacques A, Briffa K. The health burden of large breasts in women aged over 40-years World Confederation for Physical Therapy Congress 2019, Geneva, Switzerland, PO-I-30-SUN2.

List of abbreviations

3D	Three-dimensional
AAS	Adjusted activity score
ANOVA	Analysis of variance
BSS	Breast size score
BMD	Bone mineral density
BMI	Body mass index
BSS	Breast size score
CI	Confidence interval
DXA	Dual energy X-ray absorptiometry
ES	Effect size
FN	Femoral neck
GRRAS	Guidelines for Reporting Reliability and Agreement Studies
HAP	Human Activity Profile
HRQoL	Health related quality of life
ICC	Intraclass correlation coefficient
IQR	Interquartile range
IR	Inferior breast radius
KI	Kyphosis index
LR	Lateral breast radius
MCIC	Minimal clinically important change
MCS	Mental component summary

MD	Mean difference
MDC	Minimum detectable change
MP	Mammary projection
MR	Medial breast radius
MRI	Magnetic resonance imaging
NDI	Neck Disability Index
NRS	Numerical Rating Scale
OMSPQ:	Orebro Musculoskeletal Pain Screening Questionnaire
OR	Odds ratio
PA	Posterior-anterior
PCS	Physical component summary
PI	Patient information (questionnaire)
PPT	Pressure pain threshold
PROM	Patient-reported outcome measure
SCM	Sternocleidomastoid
SD	Standard deviation
SEM	Standard error of the measurement
SF-36	Medical Outcomes Study Short-Form 36 Health Survey
TK	Thoracic kyphosis
TL	Thoracic length
TW	Thoracic width
UBP	Upper back pain
VAS	Visual Analogue Scale

Table of Contents

Chapter 1   Introduction, review of the literature and rationale for thesis

1.1   Introduction

1.1.1   Upper back pain: definition, prevalence and overview

Upper back pain (UBP) is a term used to describe pain in the region of the thoracic spine. Unlike lower back pain and neck pain, the prevalence and aetiology of UBP has not been examined widely and risk factors for the condition remain relatively undetermined. The upper back is a complex region of the body with close interdependent anatomical relationships with the shoulder, neck, and lumbar spine. In addition to musculoskeletal causes of UBP there are many neural, vascular, and visceral structures that refer to this region, adding complexity to understanding its aetiology. As a result of being poorly and inconsistently defined in prior epidemiological research, estimates of UBP prevalence are highly variable, with reports of between 6% (12-month prevalence)[1] and 72% (point prevalence)[2] for populations which differ by age, gender, and pain duration. Females in general, however, consistently show a greater prevalence of UBP[2-5] and UBP appears to become most troublesome for women after middle-age[4] with a spike in prevalence[1] and severity[4] around the age of 75-80 years. Understanding the factors that are associated with likelihood and severity of UBP in mature-aged women (women of middle-age (40-years) and older) has the potential to advance clinical practice by guiding health professionals on relevant targetable characteristics for the management of the condition in these women. Mature-aged women represent the fastest growing proportion of the Australian general population[6]. Identifying risk factors for musculoskeletal conditions such as UBP is a key priority in the national strategy to promote the healthy ageing of women in Australia[7]. It is also an important step in reducing the substantial health and economic burden attached to chronic musculoskeletal back pain conditions[8, 9].

1.1.2   Upper back pain in mature-aged women and the spectrum of related factors

In prior epidemiological research only two factors, concurrent musculoskeletal complaints and difficulties with activities of daily living, were identified as being associated with UBP in adults[2]. It was not clear, however, whether these were age or gender-specific. The general paucity of risk factors identified for non-idiopathic UBP in adults was highlighted by this review[2] with only 4 of the 33 papers included examining adult populations. Knowledge has not advanced greatly since this 2009 review and the inadequate and inconsistent definitions

of UBP in addition to a lack of validated UBP measures make it difficult to identify factors associated with the condition.

Many physical characteristics that have a direct mechanical relationship with the upper back could be potentially associated with UBP. The change in upper torso mechanics that occurs in women with ageing and after menopause and that is well-described[10-12] provides good rationale for examining UBP in relation to these. At present, changes such as bone dimeralisation[13, 14], the increasing prevalence of vertebral fractures[15], and increasing thoracic kyphosis[13, 16-18] have been more commonly examined in clinical populations of mature-aged women for the purposes of characterising presentations such as osteoporosis rather than for the purpose of explaining UBP. Spinal stiffness[19], back and trunk muscle weakness[20], and progressive postural changes[10], that also occur in women with age, popularly attract clinical attention. Despite anecdotal links with UBP, these age-related changes have also had limited formal examination as risk factors for UBP in healthy mature-aged women.

In addition to physical factors, considering aspects of health and psychological wellbeing that could include psychosocial, behavioural, and lifestyle characteristics, is an important step towards acknowledging the biopsychosocial nature of UBP[2]. A multidimensional approach to the management of musculoskeletal pain conditions is now widely advocated[21] and this encourages exploration of a broad spectrum of potential related factors.

1.1.3   Introducing breast size as an associated risk factor for upper back pain

Breast size as a factor possibly associated with UBP in women is the focus of this thesis. Although UBP is a common complaint in women of varied age with large breasts[22-26], breast size has not been adequately examined as a risk factor for UBP in mature-aged women. Breast size is descriptively linked to UBP via putative biomechanical mechanisms[23, 24, 27]. Early theories describe musculoskeletal tissues that are placed under strain from the postural adaptations to large breasts[27]. Whilst it is plausible that there is a physical basis for UBP in women with large breasts, this presently remains understudied.

Mature-aged women describe an increase in breast size with ageing[28] and following menopause[29]. The physiological basis for changes in breasts with age that include an increase in size and ptosis (drooping), is well-described[30-33]. These changes are inevitable for women and although there is qualitative evidence describing the negative effects of these changes on how women feel about their breasts[28, 34] and their bodies in general[35], it is not certain that these changes affect the UBP they experience.

1.1.4   Summary and thesis aim

Upper back pain that is common in mature-aged women has a broad range of possible related factors including physical and non-physical characteristics. Breast size is a physical characteristic that changes alongside a myriad of others in women as they age. These may individually or collectively pose as risk factors for UBP. The overall aim of this thesis was to investigate the relationship between breast size and UBP in mature-aged women.

1.2   Breast size and upper back pain

1.2.1   Fields of study and terminology

Information regarding the relationship between breast size and UBP comes from two lines of research involving women of varied age that use different methods to examine breast size and measure UBP. One line of research includes longitudinal studies that involve women with large or excessively large (hypertrophic) breasts seeking a surgical reduction in their breast size (reduction mammoplasty). Upper back pain and other health-related outcomes have been examined preoperatively and postoperatively to convey the burdens attributable to increased breast size and the functional benefits of the procedure. A much smaller second line of research includes cross-sectional studies involving adult women with a range of breast sizes who were not seeking reduction mammoplasty. Upper back pain and other physical characteristics have been examined in these women with the purpose of identifying differences according to breast size.

Breast size is quantified differently across studies in both lines of research. The difficulties of measuring breast size are well-acknowledged[36-39] and there is no agreement on the most valid method for estimating breast size. The varied shape, position, density, and symmetry of breasts provides a challenge for the accurate measurement of their size, weight, and volume. Some of the common methods used for measuring breast size are reviewed in Chapter 4. In addition to inconsistent units of measure, breast size is commonly categorised within the literature using descriptors such as 'small', 'medium', 'large' and 'hypertrophic'. The definitions of these descriptors is also inconsistent across studies which makes it difficult to identify trends in the research. In studies of women undergoing reduction mammoplasty, the amount of resected breast tissue which is indicative of the size of breast reduction, is usually measured as a weight in grams, but there is often variability in how this is reported (unilaterally/per breast or bilaterally/in total).

1.2.2 Upper back pain in women with large breasts

The prevalence of UBP, whilst not having been formally examined as a specific condition in large populations of women with varying breast sizes, has been speculated to be higher in women with larger breasts[22-26].

Upper back pain has been reported to affect between 82%[25] and 97%[26] of women seeking reduction mammoplasty and whilst this is commonly rated at mild-to-moderate severities preoperatively[25, 40-42], it is a primary reason reported by women for seeking reduction mammoplasty[43]. Of note, physical symptoms such as UBP are noticeably more common in older women than in younger women pursuing this type of surgery[44] and it is widely-acknowledged that women of older age are more motivated towards the functional rather than cosmetic gains from reduction mammoplasty[43, 45, 46]. This could suggest that breast size becomes more symptomatic and/or problematic for women in their mature years.

Only one prior study has examined postmenopausal women not seeking reduction mammoplasty specifically[24]. In this study (n=50) larger breast size was significantly associated with thoracic spine pain measured using a generic pain questionnaire and body size was considered to be a potential confounder. Women recruited for this study had a reasonably diverse range of bra sizes (10A to 22E). By comparison, in a smaller study (n=30) of younger women (aged 18-26 years) with overall smaller and less diverse bra sizes (10A to 14F) but using the same thoracic pain outcome measure, breast size was reported to be unrelated to thoracic pain[47].

Upper back pain has also been assessed as part of a composite upper torso musculoskeletal pain score which included pain felt in the neck, shoulders, arms, lower back, breasts, and head[23]. In the study by McGhee et al[23], greater severities of pain were reported in women with large breasts (>DD-bra cup size) compared to women with women with small breasts (A/B-bra cup size)[23]. However, it was not clear whether the severity of UBP was specifically rated higher because it was assessed and analysed as part of the composite score that included seven body regions. Subsequently, in a larger study (n=300) of women (aged18-82 years) grouped according to breast volume that used the same upper torso musculoskeletal pain score measure, overall pain severities were reported to be 60% greater in women with hypertrophic (>1200ml) breasts compared to women with small (<350ml) breasts and significant differences were highlighted specifically for the upper back region[22]. In addition, it was noted from this larger study that women with hypertrophic breasts were also the oldest participants (mean age 51 years) and there was a trend of increasing age across the breast size groups from small through to hypertrophic[22]. Collectively, the trends in both cross-

sectional data of women not seeking reduction mammoplasty and data provided from reduction mammoplasty studies, suggest a relationship between breast size and UBP may be particularly noticeable amongst mature-aged women.

1.2.3 Upper back pain related to breast size: in theory

The early observations of women seeking reduction mammoplasty provided a basis for the widely-accepted putative biomechanical mechanisms that now link breast size to UBP. According to the descriptive accounts of Letterman and Schurter[27], the downward drag of heavy pendulous breasts anteriorly on the chest caused the forward displacement of the body's centre of gravity as the trunk and upper back became habitually more flexed. An increased thoracic kyphosis, forward head posture, and rounded shoulders were considered the common postural adaptations to large breasts. These postural adaptations were thought to place strain on musculoskeletal tissues which in turn provided a basis for symptoms. Degenerative changes affecting the cervical and thoracic intervertebral joints were hypothesised as the possible source of skeletal pain and tight cervicothoracic muscles, the source of muscular pain. The theory has gone largely unchallenged in the intervening years and a growing body of evidence now exists to loosely corroborate parts of the theory.

Studies involving women undergoing reduction mammoplasty have compared selected physical characteristics such as posture[48, 49], thoracic kyphosis[40, 50-52], and upper torso muscle strengths[49] preoperatively and postoperatively to examine how these change in response to reducing breast size. Very few of these changes, however, have been examined alongside UBP and so the relevance of the physical characteristics and their change to UBP has not been confirmed in most studies.

Studies involving women who are not undergoing reduction mammoplasty have examined physical characteristics such as thoracic kyphosis[22, 24, 53, 54], thoracic flexion torques[22, 23], posture[55, 56], shoulder range of motion[23], and scapular retractor strength endurance[23] in women of different breast sizes and specifically focus on how these vary in relation to breast size. Several of these studies[22-24] have also assessed UBP, but only one study[24] has previously examined UBP as an outcome related to the physical characteristic and breast size.

In only one study has biomechanical modelling been used to examine breast forces on the spine[57]. Additionally, in only one other study have degenerative changes of the spine been examined in relation to breast size[45].

1.2.4   Factors related to breast size: biomechanical modelling

Thoracic kyphosis

Thoracic kyphosis describes the curvature of the spine in the sagittal plane. Thoracic kyphosis angles of between 20-40° are considered normal[234]. An accentuated thoracic kyphosis is a central tenet of biomechanical theories linking larger breast sizes to UBP. It is the most widely-examined spinal posture related to breast size[22-24, 40, 50-53] yet there is still insufficient evidence to support the place of thoracic kyphosis as a consequence of larger breasts or a precursor to UBP as theories suggest[27]. The method used for assessing thoracic kyphosis varies across studies with a mixture of radiological and non-radiological techniques employed. In women with large breasts seeking reduction mammoplasty, radiologically determined average thoracic kyphosis angles as low as 36.2° (n=30)[50] and as high as 59.9° (n=40)[40] have been noted preoperatively across four studies[40, 50-52]. Thoracic kyphosis angles preoperatively have not always been observed in those women with the largest breasts[40, 52], but in all[40, 50, 51] but one[52] surgical study, thoracic kyphosis angles were reported to reduce significantly following the procedure. These findings, which are limited to small (n=<40) samples of women with hypertrophic breasts or macromastia, where breast weight exceeds 3% of body weight[58], provide some evidence that supports the theory that an accentuated thoracic kyphosis is a pathological outcome of having large breasts and that this normalises by reducing breast size. It is not clear, however, whether improvements in thoracic kyphosis are contingent on the amount of breast tissue removed as conflicting results have been provided in the two studies that examined this[40, 51]. It is also not certain how changes seen in thoracic kyphosis pre-to-post-surgery relate to UBP as this has been reported in only one surgical study[40]. An 81% improvement in average UBP severity measured using a Visual Analogue Scale (VAS) was reported alongside average changes in thoracic kyphosis angle of 17° and total breast resections of up to 3763g[40]. It has yet to be verified if changes in thoracic kyphosis or indeed breast size, need to be this substantial in order to gain symptomatic improvement.

Amongst women with a broader range of breast sizes who are not seeking reduction mammoplasty, thoracic kyphosis has been examined radiologically in only one study (n=93), where women (aged 18-49 years) with large (D-bra cup size) breasts had significantly greater kyphosis angles than women with small (A-bra cup size) breasts[53]. With women categorised into similar breast size groups, but who were of more diverse ages, this significant difference has been confirmed more recently in a small study (n=51) of women (aged 18-60 years)[23] but not in a larger study (n=300) of women (aged 18-82 years)[22]. In both of these more recent studies thoracic kyphosis was assessed using Flexicurve, a non-

radiological measure of thoracic kyphosis that has been deemed reliable[59-63] but not necessarily valid[64]. Although there are inconsistencies in research as to whether thoracic kyphosis varies according to breast size, which may in part relate to the different measurement methods used, women not seeking reduction mammoplasty[22, 23, 53] consistently show far lower average thoracic kyphosis angles than those seen in most women preoperatively in reduction mammoplasty studies[40, 51, 52]. This suggests that the pathological effect of breast size on thoracic kyphosis may only be generalisable to women whose breasts are very large. Since the majority of studies, both surgical and non-surgical, have compared thoracic kyphosis angles across women grouped by their breast size, it is also still unclear whether a strong linear relationship exists between breast size and thoracic kyphosis. Consequently, there is insufficient theoretical support that thoracic kyphosis is a key biomechanical outcome of larger breasts. Furthermore, in the absence of work that explores the clinical meaningfulness of changes in thoracic kyphosis following reduction mammoplasty, claims of symptomatic relief related to this are presently unsubstantiated.

Posture

Variations in posture between women of different breast sizes has had limited objective exploration despite posture being implicated in the experience of UBP in women with large breasts[27]. A more forward head, more rounded upper back, and more protracted shoulders, are considered postural adaptations to larger breast sizes[27] and these misalignments are examples of where there is deviation away from the body's normal line of gravity. Upper back posture is descriptively similar to thoracic kyphosis and it is not uncommon for these terms be interchanged. It is likely, however, that upper back posture and thoracic kyphosis are distinct characteristics in postmenopausal women, with thoracic kyphosis being more indicative of a permanent structural misalignment that may develop from habitual postures[12].

The varied aetiology of posture makes it a challenging characteristic to examine because of influences that include, but are not limited to, physical, psychological, and occupational factors. Early theories of UBP related to breast size focus on the physical reasons for postural changes in women with large breasts, and consequently, a biomechanical mechanism involving head, upper back, and shoulder posture is what has been most commonly examined[48, 55, 56, 65, 66]. Psychological factors that may also affect posture in women with large breasts, such as breast embarrassment or anxiety that leads women to try to conceal their breast size, although speculated to be influential[66], have received far less attention.

From the observation of 11 women (mean age 31 years) undergoing reduction mammoplasty, Goulart et al[48] used a reliable photogrammetry method to demonstrate

significant improvements in the horizontal alignment of the pelvis and smaller improvements in the alignment of the shoulders and trunk 90-days after reduction mammoplasty (mean total resection weights of 1848g). Upper limb and spine pain reduced alongside the improvements in pelvic alignment to suggest the positive benefits of reduction mammoplasty on posture and breast-related postural symptoms. The links between horizontal pelvic alignment and relief of pain in the upper limbs and spine were, however, not clearly stated, and with only one of eight posture angles showing a significant change, the effect of reduction mammoplasty on posture may have been overstated by this small study.

Subsequent to the study by Goulart et al[48], using a three-dimensional (3D) gait analysis system, Sahin et al[67] demonstrated a 41% reduction in anterior pelvic tilt in 11 women aged 34-65 years following reduction mammoplasties of comparable size (mean total resection weights of 1693g). Preoperative pelvic tilt angles were regarded as abnormal with respect to normative data, and by showing the normalisation of pelvic angles postoperatively, Sahin et al[67] provided some clinical meaningfulness to their results. Despite lower back pain not being assessed in this study, lower back pain was loosely discussed in reference to changes in pelvic alignment. Interestingly, Sahin et al[67] also reported that improvements in pelvic angle looked to be proportional to amount of breast tissue resected. Due to their small sample size, however, they did not examine this statistically.

In a larger study (n=42), where back inclination angles were measured using a different photogrammetry method, no significant change in back posture was recorded for women (mean age 36 years) following reduction mammoplasty (total resection weights 312g-2155g), despite significant relief of 'back pain' being reported[65]. A strength of the method used in this particular study was that back inclination angles were determined from ten replicate measurements from photographs, which may have reduced measurement error. There were, however, no estimates of reliability provided for the method employed and it was unclear if photos were analysed by the same assessor. The extended postoperative follow-up period in this study (mean of 4.3 years) may have also limited their findings, where any number of factors including increasing age and body mass index (BMI) (alluded to in the study) could have been influential.

Outside the reduction mammoplasty literature, there have been inconsistent trends in cervical and thoracic postures noted in women of different breast sizes. In a study that used a 3D system to examine 15 young women (mean age 23 years) with a small range of breast sizes, larger breast sizes were associated with more lordotic cervical posture but not with a more kyphotic thoracic posture[55]. Head and shoulder protraction were speculated as outcomes related to these findings but, as postural deviations, these were not specifically examined.

The results did, however, highlight the variations in cervical and thoracic posture angles that come from measuring angles in different positions (slumped versus upright), underlining the potential importance of participant positioning when acquiring photographs of their posture.

A small study of 22 young women (mean age 23 years) completed a few years earlier using photogrammetry recorded no differences in head and scapular position between women with large breasts (≥D- bra cup size) and women with small breasts (≤B-bra cup size)[56]. It was also noted in this study that upper torso discomfort measured using a VAS was not significantly different between these groups of women. Although this was unexpected, it was at least consistent with not finding any differences between groups in terms of posture. The reliability of the methods used in this study, however, were not described and its small sample size was a major limitation.

There is a lack of clear evidence to support that posture is altered as a consequence of breast size. Whilst there may be good theoretical underpinning for larger breasts to cause postural deviations such as a more forward head, a more rounded upper back, and protracted shoulder position, the objective evidence to support this is limited. Furthermore, there is not convincing evidence that the changes in posture after reduction mammoplasty explain relief from UBP. Reduction mammoplasty studies in this area typically involve small numbers of participants and thus more studies with more participants are needed to provide a weight of evidence that posture changes significantly after surgery. The mechanisms of symptomatic relief related to these posture changes are also not well-described by these studies. Symptoms are often inadequately defined by region and the mechanisms of how changes in posture alleviate symptoms is not postulated clearly. Examining the posture of much larger samples of women with a range of breast sizes could clarify the inconsistencies that have been noted in small studies of women not seeking surgery. The age of women may also be a relevant consideration. Postural deviations related to large breasts may be more likely in older women who, perhaps, have physiological reasons that make carrying larger breasts more of a challenge to maintaining good body posture[24]. Age-related changes in upper back and torso mechanics may be considered as some of these reasons and these are described more fully in section 1.3.

Biomechanics

The biomechanical basis for theories of UBP related to larger breast sizes has received some attention. Using sophisticated motion tracking equipment to examine the centre of mass of women undergoing reduction mammoplasty, Mazzocchi et al[66] demonstrated an immediate change in the centre of mass in 52 women (aged 29-46 years) following total breast resections of 205-1100g. Head, shoulder, and knee centre of mass but not pelvis centre of

mass, varied significantly between pre and post-surgery and women stood with their weight concentrated more posteriorly. These changes occurred early, within one month, in the postoperative period and were attributed to the emotional and psychological responses to surgery although these were not specifically examined. The results of this study provided some indication that reducing breast size leads to postural rearrangement which is mostly towards an improvement by reducing anteriorly-directed forces. However, without a control group to compare to and with limited information provided on the participants during the postoperative period (e.g. physical activity levels, pain, perceptions), it is difficult to be certain that the changes were entirely attributable to the surgery.

Using biomechanical modelling, one prior study has reported that there are elevated compressive forces acting on the thoracic spine with increasing breast size (breast weight)[57]. Forces were evaluated in this study with the thoracic spine modelled in a good posture. In women with large breasts who commonly assume more kyphotic thoracic postures[53], it is possible that spinal loading could be far greater than was estimated in this study[68]. A further limitation of this study was that breast weight was estimated from bra sizes, a system which has not yet been validated. Furthermore, differences in breast density, which may affect breast weight, were not accounted for in breast weight calculations.

Thoracic flexion torque is another characteristic that has been examined in relation to breast size. Two studies have used an identical calculation method for estimating thoracic flexion torque related to breast size based on breast weight and breast moment arm length[22, 23]. Both studies indicated that thoracic flexion torques increase with larger breast sizes. The smaller study (n=51)[23] reported average thoracic flexion torques that were five times higher in women (mean age 45 years) with large breasts (breast volume >1200ml) compared to women with small breasts (breast volume <800ml). The larger study (n=300)[22] reported thoracic flexion torques that were three times higher in women with hypertrophic breasts (>1200ml) compared to women with small (<350ml) breasts. Although these studies suggest that thoracic flexion torques increase with breast size, as torques were examined between breast size groups, which varied by definition, it cannot be assumed that a linear relationship exists. Furthermore, there was clear variability in the torque estimates between these studies as demonstrated in their mean data tables. Average thoracic flexion torques (3.7Nm, 95%CI: 3.4-3.9Nm) for women (n=34) with hypertrophic breasts who had average total breast volumes of 3322ml in the larger study[22] for example, were far less than the average thoracic flexion torques (5.9Nm, 95%CI: 4.5-5.8Nm) for women (n=27) who had much smaller average total breast volumes (2373ml) in the smaller study[23]. This suggests that either

thoracic flexion torques are highly variable for women with very large breasts, or that there could be inaccuracies in the calculation method used.

Whilst this small group of studies provide some support for the effect of larger breasts on biomechanical variables, it is not clear that these effects contribute to the clinical picture of UBP. Several studies[22, 54, 57] speculate that symptoms are related to differences in biomechanical variables but this has not been formally examined. Furthermore, other factors which may vary between participants and influence biomechanical variables have been given little consideration across most studies. There appears to be wide scope for the investigation of other biomechanical factors that may account for UBP in women with large breasts, including the loading of intervertebral discs from changes in trunk position[68a] and trunk muscle[68b] activity. If breast weight proportional to size heightens thoracic flexion torques and elevates vertebral compression forces, intervertebral discs are likely to be exposed to greater loads which may in turn accelerate degenerative processes, causing pain. Relevant to furthering our understanding of the biomechanical implications of large breast sizes, could be the existing work showing that upright loaded body positions[68a] and anteriorly translated trunk positions[68b] contribute to greater intervertebral disc loading.

1.2.5   Explaining upper back pain in women with large breasts

The source of UBP in women with large breasts has been considerably understudied despite the strong theoretical underpinning that there is a physical basis for such symptoms[27].

There has been only one prior study conducted to confirm that larger breast size may have pathological consequences for the spine[27]. By examining the magnetic resonance imaging (MRI) scans of 50 young women (mean age of 28 years), the study by Beditte-Klepetko et al[45] determined that the relative risk of degenerative changes (including disc protrusion, narrowing of the intervertebral disc space and/or foraminal stenosis) affecting the cervical and thoracic spine, was increased 2.7-fold for each additional kilogram of breast weight (calculated from volumetric measurement of the breast). Degenerative findings on MRI (indicated by a higher 'MRI score') were also related to a composite spine function score which included measures of back strength, neck mobility, and shoulder position. As a composite score, it was not clear which aspects of spine function were of greater or lesser importance to the relationship with MRI score but overall, poorer spine function correlated with higher MRI scores. It was also reported in this study that 'back pain' severity, quantified by VAS, correlated significantly with breast weight and MRI scores. As such, it provided the first objective evidence that there could be a physical basis for symptoms related to breast size. There were several limitations of this study, however, including that

the degenerative changes noted on MRI and back pain were not localised to specific regions of the spine. Also, it was unclear which degenerative changes were most common and how extraneous factors such as congenital abnormalities or prior trauma were accounted for during MRI analysis.

In another small study (n=50) that examined the thoracic spine in postmenopausal women (mean age 69 years) using a pain provocation test (Maitland-based central posterior-anterior applied (PA) pressures), larger breast size was related to specific tenderness of T7 and T8 to suggest this region as a symptomatic site in women with larger breasts[24]. It was speculated in this study that scapular retractor muscles regional to T7/8 were the potential source of this tenderness, although other potential sources, particularly those likely in postmenopausal women (e.g. thoracic fractures, osteoarthritis), were not controlled for.

There is currently insufficient evidence to confirm that musculoskeletal strain is the source of UBP in women with large breasts. In addition, it is unclear that UBP specifically is related to skeletal and muscular changes occurring as a result of having larger breasts. As such, early theories remain unsupported. In the absence of studies examining musculoskeletal tissues within the upper back across women of different breast sizes, there is presently little objective evidence to support that, as a result of increasing breast size, musculoskeletal tissues differ in structure, function, or sensitivity. Furthermore, there has been no examination of musculoskeletal tissue changes occurring in women following reduction mammoplasty to confirm any response in these tissues to reducing breast size.

1.2.6   Improvements with reduction mammoplasty

Upper back pain

The reduction mammoplasty literature has provided much of the current knowledge on the effects of breast size on UBP and by deduction rather than prospective investigation, a cause and effect relationship has been relatively well-established. Drawing on the findings of these studies, back pain is largely resolved following reduction mammoplasty[25, 26, 40, 41, 69, 70]. Severities of back pain subjectively improve from moderate to mild levels where this has been measured using VAS[25, 40]. Unfortunately, the regional location of 'back pain' is not well-reported across these studies. Where UBP has been examined as a distinct condition, pre-to-post-surgery changes in severities from severe-to-mild[70] and from mild-to-absent[42] have been reported. Of interest, improvements in back pain/UBP were unrelated to how much breast tissue was removed in the majority of studies[25, 26, 41, 42]. Only one study[40] has reported that improvements in back pain were linearly related to the size of reduction. A point that has been often overlooked as an influence on pain improvement following

reduction mammoplasty is the expectations of participants. The majority of women seeking surgery do so for the purpose of improving their UBP[43] and undoubtedly their expectation regarding improvement is a source of bias when examining change in UBP.

In most studies, improvements in back/UBP pain have been largely attributed to the reduction of breast size with little consideration of other factors that may also contribute to this improvement. As has already been alluded to, physical characteristics that change with reduction mammoplasty have not been widely-examined in the context of UBP, providing little rationale that there is a physical basis for the improvement in UBP severities. Furthermore, symptomatic relief following reduction mammoplasty is usually assessed overall, rather than by the nature or location of symptoms. Often UBP is just one of a number of physical symptoms that are assessed collectively which makes it difficult to distinguish if UBP independently improves and by how much relative to other symptoms.

Health and psychological wellbeing

The burden of larger breasts goes far beyond UBP and there is a large body of evidence that indicates that aspects of health and psychological wellbeing are negatively related to larger breast size but improve in women following reduction mammoplasty. These include: quality of life[46, 70-74], body satisfaction[75], breast satisfaction[46, 73, 76], depression[77, 78], and physical activity levels[26, 69, 70]. Improvements in these characteristics occur as early as one-month following surgery[73] and are maintained up to 5-years post-surgery[79]. The emotional response to reduction mammoplasty is something that has not been formally examined but could have an important role in explaining the immediate improvements in health and psychological wellbeing that occur following reduction mammoplasty. The procedure is associated with few serious complications[80] and satisfaction with surgery are consistently reported to be high[46, 73, 76]. These are also likely to influence the rate and magnitude of improvements that are seen.

Despite an improvement in many aspects of health and psychological wellbeing following reduction mammoplasty, these, similar to the physical improvements, have had limited discussion in the context of UBP. It is possible that health and psychological outcomes could also explain the improvements in UBP. After all, compared to physical characteristics, health and psychological wellbeing characteristics are more widely researched and seem to improve more consistently. Understanding how aspects of health and psychological wellbeing relate to UBP specifically could help to validate this relationship. In addition, the relationships between breast size and aspects of health and psychological wellbeing need to be established for women not undergoing reduction mammoplasty to be more certain that breast size is a

factor that is independently related to health and psychological wellbeing in women more generally.

Presently, health and psychological wellbeing outcomes from reduction mammoplasty have been measured over different time frames and often in isolation from one another. There could be considerable insight gained from measuring these outcomes as a collective group and assessing the change relative to physical characteristics and UBP. Information on the nature, rate, and magnitude of characteristic changes in relation to UBP following reduction mammoplasty could help establish a basis for symptom improvement and a better understanding of the relationship between breast size and UBP. Currently, most of the improvements conferred by reduction mammoplasty are not only largely subjective (self-reported)[81] but also seem to be unrelated to the amount of breast tissue resected[25, 26, 41, 42]. This immediately brings into question whether the physical changes related to breast size following surgery are as crucial to improving symptoms as the changes in perceptions of health and psychological wellbeing.

1.2.7   Summary

Despite the recent growth in attention that the topic of breast size and UBP has received, there are still several aspects of the relationship between breast size and UBP that remain uncertain. This is particularly the case for mature-aged women who, as a specific population, have been studied less widely in both surgical and non-surgical studies. Upper back pain itself has been inadequately defined, poorly reported or assessed as part of a myriad of other physical symptoms related to breast size in populations of diverse age. There is no agreement on the mechanism by which breast size relates to UBP and whilst it remains a popularly-held belief that there is a physical basis for symptoms, this warrants further investigation. There is currently no rationale for accepting that larger breast sizes are related to other physical characteristics that account for UBP. Physical changes occurring alongside UBP following reduction mammoplasty are not well-researched. There is limited evidence supporting that physical changes are essential for UBP improvement following reduction mammoplasty. The changes in aspects of health and psychological wellbeing following reduction mammoplasty, which have received much greater research interest overall, have unclear relationships with UBP.

1.3   The changing upper torso with age and upper back pain

The following sections (sections 1.3.1 to 1.3.6) provide brief narratives of the age-related changes in physical characteristics occurring in women that have had some examination in relation to UBP. Although this work has been largely undertaken using clinical populations

of postmenopausal women and may therefore have limited applicability to non-clinical populations of mature-aged women, it nevertheless provides some indication of characteristics important to consider relative to, and alongside breast size, as potential risk factors for UBP in mature-aged women.

With the physical basis for a breast-related burden in mind, several studies speculate that increasing breast size may have a more pronounced effect on UBP in mature-aged women[23, 24, 44, 56]. The change in upper torso mechanics with age is one factor that could make increasing breast size a greater biomechanical burden for these women. Although the biomechanical basis for UBP in women with larger breasts remains largely theoretical, for mature-aged women who are likely to experience an increase in breast size at the same time as experiencing a change in the mechanical properties of their upper back and torso, the potential for UBP could be magnified.

1.3.1   Age-related change in thoracic kyphosis

The propensity for a more kyphotic thoracic spine in women as they age is noticed both clinically and in research[10]. The increase in thoracic kyphosis amongst women between the ages of 40-70 years is well-evidenced[11, 12, 82]. Amongst women of older age (>65 years), increased thoracic kyphosis is accompanied by a significant loss in height[83] and a more forward head posture[84]. Whilst there is a significant mechanical loading implication of increasing thoracic kyphosis, where vertebral and muscle compressive and shear forces are significantly higher[68, 85], there is no consensus in the literature as to whether or not women with greater thoracic kyphosis report greater UBP[13, 83].

1.3.2   Age-related changes in bone

In addition to the postural habits formed over a lifetime there are age-related changes in bone tissue that may be relevant to the clinical picture of UBP. Age-related decreases in bone mineral density (BMD) are rapid in early postmenopausal years and are associated with a concomitant decrease in bone strength[86]. The relative risk of vertebral body fractures increases by 1.5 times for each 0.1g/cm² decrease in femoral neck (FN) BMD[87]. Vertebral fractures are more likely in women following menopause and with advancing age[88]. Prevalence rates increase from 16% for women aged over 50 years[89] to 34% for women aged over 80 years[90] where similar definitions of vertebral fracture have been used (vertebral anterior or posterior height > 3SD below sample mean). Thoracic vertebral fractures are reported to account for approximately half of the variation in thoracic kyphosis among women aged between 62-90 years[91] and most commonly occur in the mid-thoracic (T6-T9) and lowest (T12) thoracic regions[92-94]. Declining BMD is an important determinant of

vertebral fractures in postmenopausal women[15, 87, 90, 95] and it is by this mechanism that UBP may be considered more likely in women with low BMD.

1.3.3 Age-related vertebral fractures

Upper back pain is a possible symptom related to vertebral fractures[94, 96] but this cannot be confirmed as vertebral fractures commonly go undiagnosed[97]. Exemplifying the uncertain relationship between vertebral fractures and symptoms, a large study of community-dwelling women aged 75-80 years showed that only 69% of women with one or more prevalent vertebral fractures reported the presence of back pain[94]. In a longitudinal study of 125 women (aged over 65 years) with osteoporotic vertebral fractures, pain severity was measured using a 100mm VAS[96]. In this study, significantly higher pain severities (VAS of 75mm) were reported in the acute period following diagnosis of a vertebral fracture than at 6-months later (VAS of 25mm), indicating that the age of the fracture could be instrumental in determining symptoms[96]. This may help to explain the variability in symptoms that have been noticed amongst women with vertebral fractures. There has been no examination of UBP in relation to prevalent vertebral fractures in healthy mature-aged women.

1.3.4 Age-related degeneration and change in back mobility

Intervertebral joint osteoarthritis is another bone-related degenerative pathology that can affect vertebral body shape[93]. In addition, osteoarthritis may also affect the capacity of the thoracic spine to move. Thoracic stiffness is a related impairment that is frequently targeted by clinicians as a potential source of UBP. Of all thoracic movements, extension in the sagittal plane is the most fundamental to upright daily tasks. Thoracic extension range of motion in both males and females has been demonstrated to be low, even in their younger adult years[98] but it typically reduces further after the age of 60 years[99]. Healthy older women (aged 66-88 years) have been observed to have significantly greater stiffness in their thoracic spine compared to younger women (aged 21-51 years). The ability to extend and straighten the upper back is estimated to be three-times less in older women compared to younger women[19]. The degree of resting thoracic kyphosis is one factor known to erroneously inflate measurements of thoracic extension range of movement[100, 101]. It is therefore critical to account for resting thoracic kyphosis when measuring thoracic mobility. Moreover, having the capability to extend could also be an important determinant of thoracic mobility. Degenerative changes and pathology affecting the thoracic intervertebral joints, the strength of thoracic extensor muscles, and back pain are related factors that could dictate this capability[102].

While clinically thoracic stiffness is often viewed as a contributor to UBP, research has not confirmed this in healthy mature-aged women. Treating thoracic stiffness is also common in clinical settings, yet in experimental settings there is not strong evidence that treating thoracic stiffness significantly improves UBP despite improvements in stiffness being reported[103]. This further brings into question whether thoracic stiffness itself is a characteristic related to UBP or whether its relationship with other characteristics could be of more relevance.

1.3.5 Age-related changes in back muscles

Back extensor strength[104] and lean muscle mass in general[105, 106] are physical characteristics that decline with age and have broader implications for the changes in upper torso mechanics in women that may also be relevant to UBP. A loss of muscle density by as much as 17% per decade has been recorded in women after the age of 40 for a number of important spine stabilising and extensor muscles, including erector spinae and transversospinalis[107]. This is occurring on a background of generalised sarcopenia where loss of between 0.31% and 0.5% muscle mass over 3-year[108] and two-year periods[109] respectively have been reported in white women aged 70-79 years.

Back extensor muscle strength has a number of important relationships with other physical characteristics including thoracic kyphosis, back mobility, and vertebral fracture risk. Reduced back and trunk muscle strength is associated with greater thoracic kyphosis[20, 110-112], less flexion and extension mobility of the spine (T1-L5)[102], and an increased risk for vertebral fractures[113]. These interactions make it challenging to ascertain if back extensor muscle strength is a factor related to UBP independently, or via its relationships with other characteristics.

Upper back extensor muscle endurance has been less-widely researched as an aspect of muscle function but could also be relevant to UBP. In contrast to strength, which is the amount of force a muscle can exert in a single maximal effort[114], endurance is the capacity of a muscle to resist fatigue[115]. With the majority of upper back extensor muscles having a primarily postural function[116], their endurance capabilities are likely to be particularly important. Normative data suggest that the age-related changes in upper back extensor muscle endurance trend similar to back strength, with declines after age 40 years and rapid declines after the age of 60 years[115].

A loss of up to 50% of peak back extensor muscle strength between the ages of 50 and 90 years[104] and back extensor muscle endurance between the ages of 40 and 80 years[115], highlight that women in their mature years may be most susceptible to the effects of poor

muscle function. Whilst UBP has not been formally investigated as one such effect, there is evidence in low back[117, 118] and neck pain[119] research that suggests extensor muscle function, be it strength or endurance, influences the risk and severity of pain felt in other spinal regions. This provides good reason to believe that the function of upper back extensor muscles could also be important to UBP.

1.3.6 Age-related change in physical activity and body mass index

Physical activity levels and BMI are two additional physical characteristics that may be related as precursors to, or as consequences of, UBP. In three large cross-sectional studies (n=4515-6796), both physical activity and BMI have been identified as risk factors for low back[120, 121] and generalised musculoskeletal joint pain[122]. The decrease in physical activity levels and the increase in BMI among mature-aged women make the role of physical activity and BMI in the context of UBP particularly important to determine. In a large Australian study of 4840 middle-aged women it was identified that approximately half were inadequately active when judged against national guidelines for physical activity[123]. In addition, a steady increase in BMI in women from the age of 50 years is reported in a number of longitudinal studies[104, 124, 125]. Increasing the level of physical activity alone holds the potential to attenuate age-related losses in bone and muscle tissues[126] whilst also reducing the odds of joint pain and stiffness[122]. It is reasonable to consider that the benefits may offset the likelihood or severity of UBP.

1.3.7 Interactions between physical characteristics and breast size

The inter-relationships that are possible between physical characteristics of mature-aged women add complexity to understanding those that are most relevant to UBP. The changing nature of physical characteristics with age also provides a challenge to defining those most important to UBP at any one time. The mechanism by which increasing breast size relates to UBP in mature-aged women could involve, or be affected by, physical characteristics that change with age. There are several characteristics that may independently make UBP more likely in women as they age, that are also key components of the biomechanical theory linking breast size to UBP.

Thoracic kyphosis as a keystone

Thoracic kyphosis is the keystone of biomechanical theories linking breast size to UBP[27]. It is also a characteristic that changes predictably with age[11, 12, 82] and progresses relative to back extensor muscle strength[20, 110-112], trunk extensor torque[20], BMI[127], the presence of vertebral fractures[91], and intervertebral joint osteoarthritis[93]. For women with large breasts who, because of their breast size, may have greater thoracic flexion torques[22, 23], higher

vertebral compression forces[57], and more widespread spinal degeneration[45], changes in thoracic kyphosis may be expected to be accelerated. Upper back pain, however, is not a certain outcome of an increased thoracic kyphosis. In healthy mature-aged women the role of thoracic kyphosis in the symptom pathway is plausible but not well-researched. It is not certain that breast size contributes to thoracic kyphosis or whether, in combination with other related physical characteristics, it contributes to the progression of thoracic kyphosis. There are a number of possible interactions between thoracic kyphosis and other physical characteristics that could be relevant to explaining UBP in mature-aged women.

1.3.8   Summary

Breast size has undefined importance to UBP relative to other physical characteristics. Breast size and other physical characteristics that change with age that could be related to the experience of UBP have been insufficiently examined as a collective group. It is unclear if mature-aged women are more susceptible to UBP as a result of their physical characteristics and if increasing breast size has an independent role in determining UBP or contributes to the experience of UBP through interactions with other physical characteristics.

1.4   Upper back pain in mature-aged women: other considerations

1.4.1   The non-physical factors

Beyond the physical characteristics of mature women that may be relevant to UBP, there are also non-physical factors, such as psychosocial, behavioural and lifestyle characteristics, that may have a role in influencing the presence and experience of UBP[2]. It is of interest that UBP has attracted such little attention with regards to these aspects of health and psychological wellbeing[2]. There has been no prior specific examination of how people with UBP differ from those without UBP on the basis of psychosocial factors alone despite these factors in particular, being acknowledged to influence the clinical course and treatment of musculoskeletal pain[128-130].

To advance specific knowledge on the relationship between breast size and UBP, the types of non-physical characteristics that may be of most interest to examine are those aspects of health and psychological wellbeing related to breast size and reported in the reduction mammoplasty literature (refer to section 1.2.6). Currently, very little is known about how the health and psychological wellbeing characteristics associated with large breasts, relate to UBP.

In addition, factors related to the physical changes experienced by mature-aged women may be important. Following menopause and with age, for example, many women are less positive about their appearance[131], have greater body dissatisfaction related to increasing body weight[35], and rate their physical and mental wellbeing lower[132]. These factors may be linked with important health behaviours such as participating in physical activity as well as with the development of UBP itself.

1.4.2 Aspects of health and psychological wellbeing related to breast size

Lower quality of life, reported to be associated with breast hypertrophy in studies of women seeking reduction mammoplasty[46, 71-74], has a potentially complex relationship with UBP. Pain is a notable domain within a number of health-related quality of life (HRQoL) measures used in breast-related research including generic measures such as the Medical Outcomes Study Short-Form 36 Health Survey (SF-36)[133] and breast-specific measures such as the BREAST-Q[134]. Pain and HRQoL are therefore going to have an inherently close, and possibly reciprocal, relationship. Low back research has several examples showing lower HRQoL to be associated with higher severities and durations of low back pain[135-137]. The relationship between UBP and HRQoL has not been previously examined but in women with large breasts, where UBP may be one of a myriad of symptoms that impose on health and function, there could be aspects of HRQoL that also play a role in driving the experience of UBP.

Deficits in breast and body satisfaction that are also noted in women with breast hypertrophy seeking reduction mammoplasty[46, 73, 75, 76] and mature-aged women in general[34, 35], may also have complex relationships with UBP. Drawing again on findings from low back pain research, it is expected that a relationship may exist. Compared to healthy controls, it has been previously reported that people aged 18-60 years with chronic low back pain rate their body image more negatively[138]. Although the reasons for this were not addressed in this cross-sectional research, the data indicated that physical activity levels may help to explain at least some of the relationship between low back pain and body image. Of note, women between the ages of 18 and 75 years with large and hypertrophic breasts are typically less physically active than women with medium or small breasts[139], providing some basis for considering the role of physical activity in linking perceptions of body satisfaction and UBP in women with different breast sizes.

1.4.3   The relevance of bra fit

Not all women with large breasts experience UBP. In addition to the characteristics that may interact to increase the likelihood and severity of UBP, those characteristics, physical or non-physical, that could reduce the likelihood and severity also need recognition. Protective characteristics, particularly those amenable to change, have significant clinical value. It has been speculated in breast-related research that a correctly-fitted bra is one modifiable way to reduce the biomechanical burden of larger breasts on the upper back[24, 47, 70, 140-142]. The biomechanical implications of a poorly-fitted bra include that the downward drag of breast weight on the upper torso is potentially amplified in women who wear their bra shoulder straps too tight in order to excessively elevate their breasts[142]. It is well-evidenced that women with larger breasts commonly wear an incorrectly fitted and sized bra[47, 140, 141, 143, 144], have a poor ability to self-select a bra that fits well[141, 144], and avoid having their bra professionally fitted[140]. Despite the consistency of trends showing that bra fit is a problem for women with large breasts, there has been no quantitative investigation of whether an ill-fitting bra increases the likelihood or severity of UBP in these women or that a correctly-fitted bra protects against this. The value of a well-fitted bra has, however, been suggested in two studies that examined the accounts of women seeking reduction mammoplasty[70, 140]. In a retrospective look at strategies used by women to relieve preoperative symptoms that included back pain prior to undergoing reduction mammoplasty, Collins et al[70] reported that a supportive bra provided full and permanent relief from symptoms in 3% of women with hypertrophic breasts who were being compared to the women seeking reduction mammoplasty. Incidentally, losing weight, another and more popular conservative strategy for reducing breast-related complaints, was slightly more effective than a supportive bra, providing permanent relief from symptoms in 8.8% of women[70]. More convincing statements were provided by Greenbaum et al[140] who reported that there were customer and fitter associated factors that contribute to women with large breasts wearing incorrectly-fitted bras. After examining women with large breasts presenting for reduction mammoplasty, they confirmed that these women typically wore bras with bands too tight and cups too big, which they reasoned would contribute to physical symptoms such as UBP. It was the opinion of these authors that improving bra fit, by addressing how bras are measured and fitted in women with large breasts, could offset the need for reduction mammoplasty for many women.

For mature-aged women with large breasts who preferentially rate the comfort and fit of their bra as being particularly important[28], bra fit may have an interesting role in UBP perceived by these women.

1.4.4 Summary

The relevance of non-physical factors to UBP in mature-aged women is currently not clear. Identifying aspects of health and psychological wellbeing that may include psychosocial, behavioural, and lifestyle factors that are associated with UBP is an important step towards characterising the condition which may improve its management. Recognising the interplay between non-physical and physical factors related to breast size that are relevant to UBP may help to advance understanding of UBP as a breast-related burden and assist in developing strategies to protect against it.

1.5 Rationale for thesis

Identifying and addressing the risk factors for musculoskeletal conditions such as UBP in mature-aged women is a documented priority of the national strategy to promote the healthy ageing of women in Australia. Upper back pain is a musculoskeletal pain condition which has had little exploration in terms of the factors with which it is associated. It has been a long-standing assumption that increased breast size has a mechanistic role in the experience of UBP but this has had limited objective substantiation. Mature-aged women, who are likely to undergo physical changes in their upper back and breasts with age, are an important population in which to consider the relationship between breast size and UBP. Identifying the relative importance of breast size amongst other potential associated risk factors for UBP and exploring plausible mechanisms has the potential to benefit the health and psychological wellbeing of mature-aged women where modifiable elements of relevant factors may be identified and targeted clinically.

Consequently, an examination of UBP in relation to breast size and other associated factors using quantitative research was considered both topical and warranted.

1.6 Thesis research questions

In addressing the overall aim of this thesis to investigate the relationship between breast size and UBP in mature-aged women, six research questions were set to direct the research activities:

1. Are larger breast sizes associated with UBP in mature-aged women?

Based on the trends noted in existing research where UBP has been examined as a common condition affecting women seeking reduction mammoplasty and where UBP has been investigated as part of a spectrum of pain in women with large and hypertrophic breasts

(refer to section 1.2.2), it was expected that UBP would be more likely in mature-aged women with larger breast sizes.

2. Are there aspects of health and psychological wellbeing, currently considered a health burden, that are associated with breast size in mature-aged women?

The burden of larger breasts was expected to extend beyond UBP to other aspects of health and psychological wellbeing. It was anticipated that negative relationships would exist between increasing breast size and aspects of health and psychological wellbeing in mature-aged women. This assumption was based on the existing self-report accounts of mature women describing their breasts (refer to section 1.1.3) and the quantitative information that has been previously gathered from women with large breasts seeking reduction mammoplasty (refer to section 1.2.6).

3. What aspects of health and psychological wellbeing associated with UBP are independent of breast size in mature-aged women?

In consideration of the biopsychosocial nature of musculoskeletal pain conditions (refer to section 1.4.1), it was expected that UBP would have identifiable relationships with aspects of health and psychological wellbeing. It was anticipated that the presence and severity of UBP would associate negatively with aspects of health and psychological wellbeing independently of breast size and that this would demonstrate its multidimensional and multifactorial nature.

4. What is the importance of breast size relative to other physical characteristics in increasing the likelihood and severity of UBP in postmenopausal women?

Considering the putative physical rationale for UBP in women with large breasts (refer to section 1.2.3) and speculation that with age, women may become more susceptible to the physical burden of their breasts, it was expected that breast size would be equally as important as other physical characteristics in explaining the presence and severity of UBP in postmenopausal women.

5. What physical characteristics related to breast size support a physical basis for UBP in postmenopausal women with larger breasts?

Assuming the theoretical proposition that larger breasts lead to postural adaptations by altering the body's centre of mass (refer to section 1.2.4), it was anticipated that breast size would show relationships with thoracic kyphosis and posture variables. In addition, since the postural adaptations to large breasts could increase the strain on upper back musculoskeletal

tissues (refer to section 1.2.3), it was expected that larger breast sizes would explain variances in the structure and sensitivity these tissues.

6. Which characteristics, relevant to UBP, that change following reduction mammoplasty, progress understanding of the relationship between breast size and UBP?

Based on the assumption that UBP in women with large breasts has a physical basis (refer to section 1.2.3), it was anticipated that characteristics that change with an improvement in UBP following reduction mammoplasty would be largely physical in nature.

Chapter 2   Methods

2.1   Design of the doctoral research project

To achieve the aim of this thesis and address the research questions two samples of women were recruited; a community-based sample of women aged ≥40 years (community-based sample, n=269) and a sample of women aged ≥18 years planning reduction mammoplasty (surgical sample, n=11). Cross-sectional methodologies were used with the first sample and subsets thereof, and a repeated measures methodology with the second sample. Data from both samples were collected in parallel between August 2016 and October 2018 and used to inform the chapters of this thesis which explore different aspects of the relationship between breast size and UBP (Figure 2.1). The doctoral research project was approved by the Curtin University Human Research Ethics Committee (RDHS 267-15).

Self-report data on aspects of health and psychological wellbeing were collected from all participants. Objective measures of physical characteristics were also undertaken in a subset of postmenopausal women from the community-based sample (postmenopausal subset, n=119) and all women from the surgical sample. Self-report and objective data were examined in relation to breast size and UBP. Two aspects of UBP were of interest in the current thesis. UBP risk, defined as the likelihood (presence) of the condition, and UBP severity, defined as the intensity of the condition. Repeated measures data collected pre-surgery and at 3, 6 and 12-months post-surgery from the surgical sample were used to assess changes occurring in response to a reduction in breast size in relation to changes in UBP. Consistencies between cross-sectional and repeated measures data were identified.

The main part of this doctoral research project was preceded by preliminary work that examined the feasibility of a range of methods used. For the purposes of this work, a separate sample of women aged ≥40 years (pilot sample) were recruited (Figure 2.1).
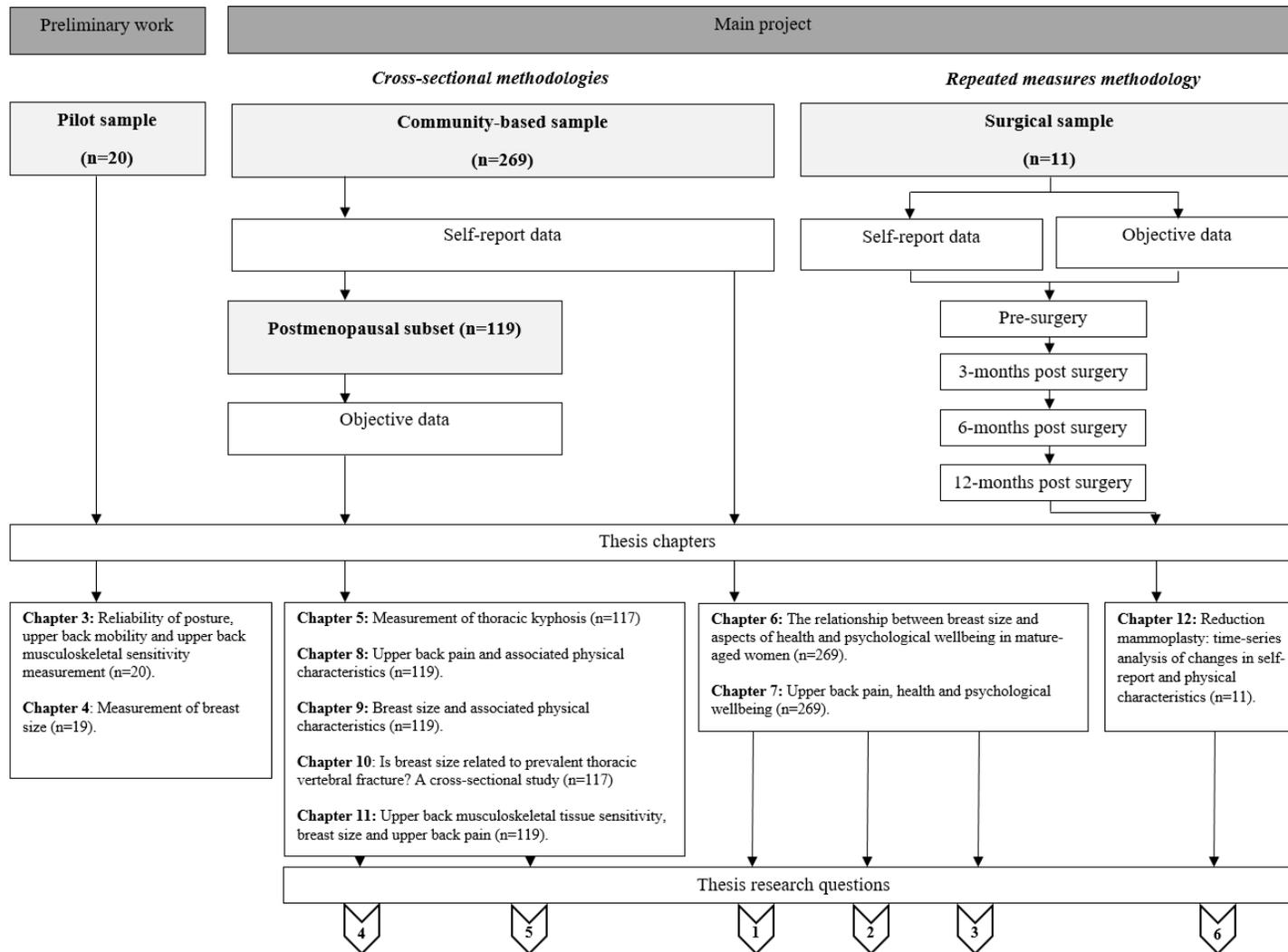
Figure 2.1 Doctoral research project design

2.2 Recruitment

Recruitment of the pilot sample is described where pilot work is presented (refer to Chapter 3). Recruitment of the community-based and surgical samples commenced simultaneously. The project was promoted as the "*Back, Breast and Bra Study*" and a website that provided information and resources on all aspects of the project supported the recruitment process (Appendix 3a). Volunteers were directed to the domain www.backbreastbrastudy.net which remained active until October 2018. The project recruited female participants only and general exclusion criteria applied to both samples (refer to section 2.2.4).

2.2.1 Community-based sample

Recruitment of the community-based sample was promoted through radio, newspaper, and poster advertisements, social media platforms, and via word-of-mouth. The age and preferences of the target population were carefully considered during the design of advertisements. For radio advertising, Curtin Radio (100.1FM) was selected as a locally-based radio station where the "over 55's" were the substantive target audience (57%)[145]. A 30-second advert promoting the project and calling for community-based volunteers was aired regularly and free of charge for a 3-month period (Appendix 3b). Listeners were directed to contact the thesis candidate who initiated recruitment. Newspaper adverts were published over two consecutive weeks in the local newspaper of a regional Western Australian retirement coastal city (Appendix 3c). Posters and leaflets were also displayed in senior citizen centres, recreational and bowling clubs, and private physiotherapy and medical centres within this city (Appendix 3d). Recruitment for the community-based sample remained open until the target sample size of 269 was reached. The target sample size (n=269) was calculated to identify an UBP prevalence significantly different from zero amongst women ≥ 40 years in the local region from which the sample was to be drawn given the prevalence data for thoracic spine pain reported previously in a review paper[2]. A sample size of 269 was deemed sufficient assuming a population of 157,500 women of this age in the greater Perth area[146] and assuming a confidence level of 95% and a confidence interval (CI) of 6%[147].

2.2.2 Postmenopausal subset

It was feasible to complete physical measures on approximately 100 postmenopausal women given the time and resources available. A priori sample size calculation for the studies including postmenopausal women showed that 100 would be sufficient to detect change in odds for UBP of 0.9 or larger with a power of 80% and a confidence level of 95%[147]. A

subset of postmenopausal women were recruited from the community-based sample using consecutive sampling. A project supervisor (LM) identified potential participants from the community-based sample with and without UBP and invitations to participate were offered by the thesis candidate who was blinded to the UBP status of participants. Recruitment continued until there were approximately an equal number of participants with and without UBP (confirmed by LM) and the sample exceeded the target of 100.

2.2.3 Surgical sample

Recruitment of the surgical sample was promoted via more specific channels. Ten breast surgeons working privately and/or publicly in the Perth metropolitan area were initially contacted and provided with information on the project. Project promotional material was supplied for display in patient waiting rooms and within preoperative information packs (Appendix 3f and Appendix 3g). In addition to meeting with a number of surgeons throughout the recruitment period, regular contact via email was made to bolster recruitment. Radio adverts on Curtin Radio, with the purpose of attracting participants, were aired for a period of 3-months once adverts for the community-based sample had ceased (Appendix 3b). Promotional material was displayed in a breast prosthesis and bra fitting shop that provided specialist services for women undergoing breast surgery in the Perth metropolitan area. Social media platforms that were also used to reach potential participants and promote recruitment included Facebook, Twitter and LinkedIn. The recruitment period for the surgical sample remained open for 18-months with a target sample size of 50 participants. In the absence of objective data on UBP in women awaiting reduction mammoplasty sample size calculations were made on the basis of feasibility according to the time-frame of this PhD. With a target sample size of 50, the study was powered to detect a minimum effect size change of f=0.17 (partial eta-squared of 0.028) in any of the continuously-measured variables using a repeated measures (paired) comparison with an alpha of 5% and a power of 80%[147]. This original power calculation was revised down given that the study ultimately recruited fewer than 50 participants (refer to Section 2.2.7 and Section 12.4.1).

2.2.4 General exclusion criteria

Volunteers were excluded from participating if they were unable to read and understand English sufficient enough to comprehend documentation, instructions, or outcome measures used in the project. Volunteers were also excluded if they resided outside of Australia. With the potential to confound the results, volunteers who had undergone previous breast surgery, or those volunteers with a history of thoracic spine surgery, a systemic inflammatory condition, a neurodegenerative disorder, or a known pathology of the breast, lung or thoracic

spine were also excluded. With the potential to confound the assessment of UBP, volunteers who had long-term and/or recent use of steroid or pain medication were also excluded.

2.2.5 Specific exclusion criteria

In addition to the general exclusion criteria, volunteers were excluded from the community-based sample if they were under 40 years of age. Participants in the community-based sample were excluded from the postmenopausal subset if they were pre or peri-menopausal[148], or had not provided contact information. Volunteers were excluded from the surgical sample if they were aged under 18 years or did not have reduction mammoplasty planned within the next 12-months.

2.2.6 Benefits of participation

Advertising material used to attract community-based sample volunteers offered, as a benefit of participation, a free bra-fitting guide (Appendix 3h). The postmenopausal subset and surgical sample also received copies of their assessment results which included a BMD assessment(s) and thoracic spine X-ray(s). As a token of appreciation for a substantial contribution to the project, participants in the surgical sample also received a $20 voucher at the end of their participation. Vouchers had been donated to the project and were redeemable at a metropolitan-based lingerie shop.

2.2.7 Responses

Recruitment of the community-based sample was achieved within an eight-month timeframe (Figure 2.2). Recruitment of the surgical sample was more challenging than expected. Because this sample was monitored for 12-months, it was not feasible to extend the recruitment period beyond 18-months. The number of participants recruited to the surgical sample fell below target (Figure 2.3).
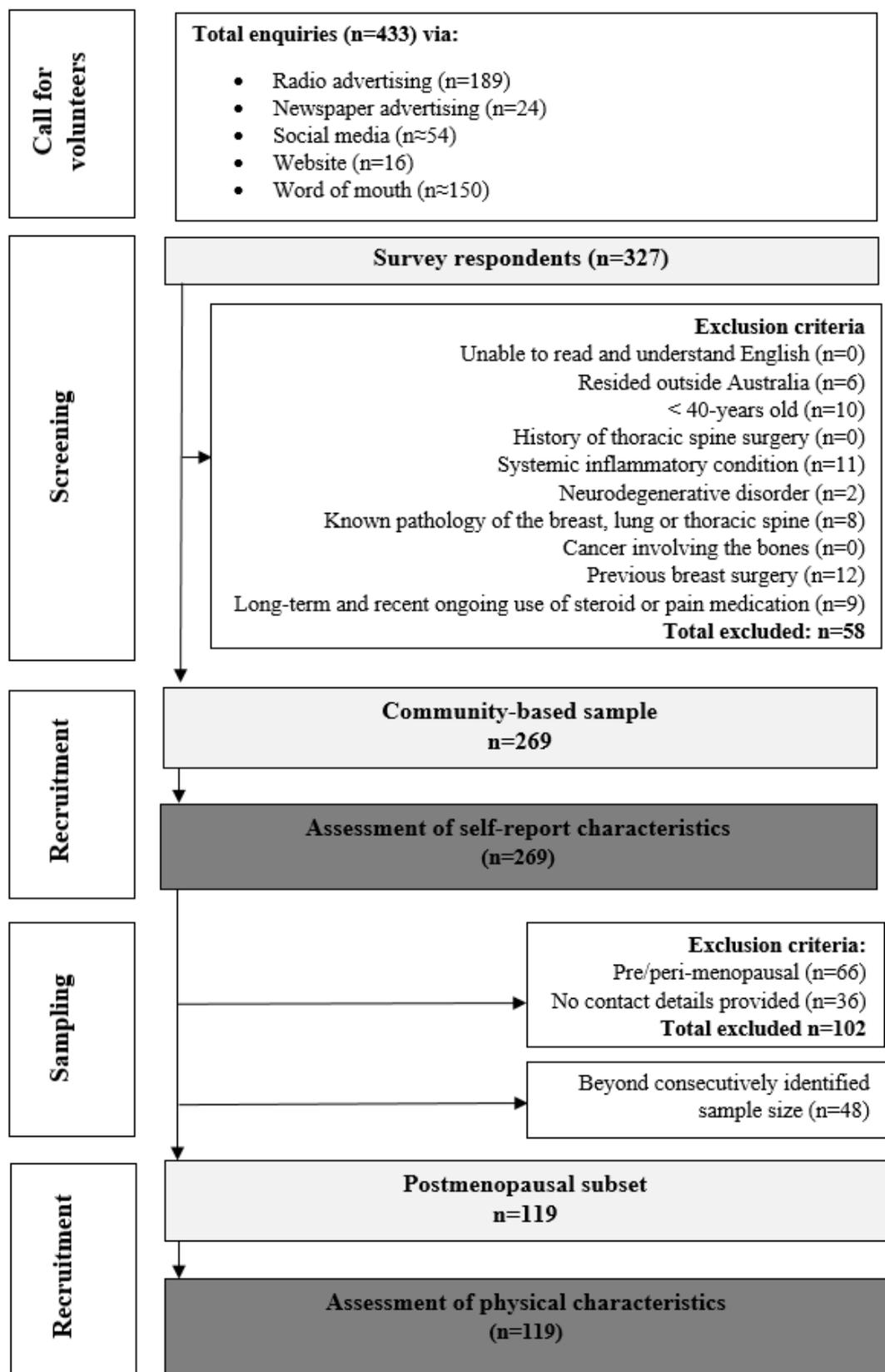
Figure 2.2 Study flow diagram: community-based sample
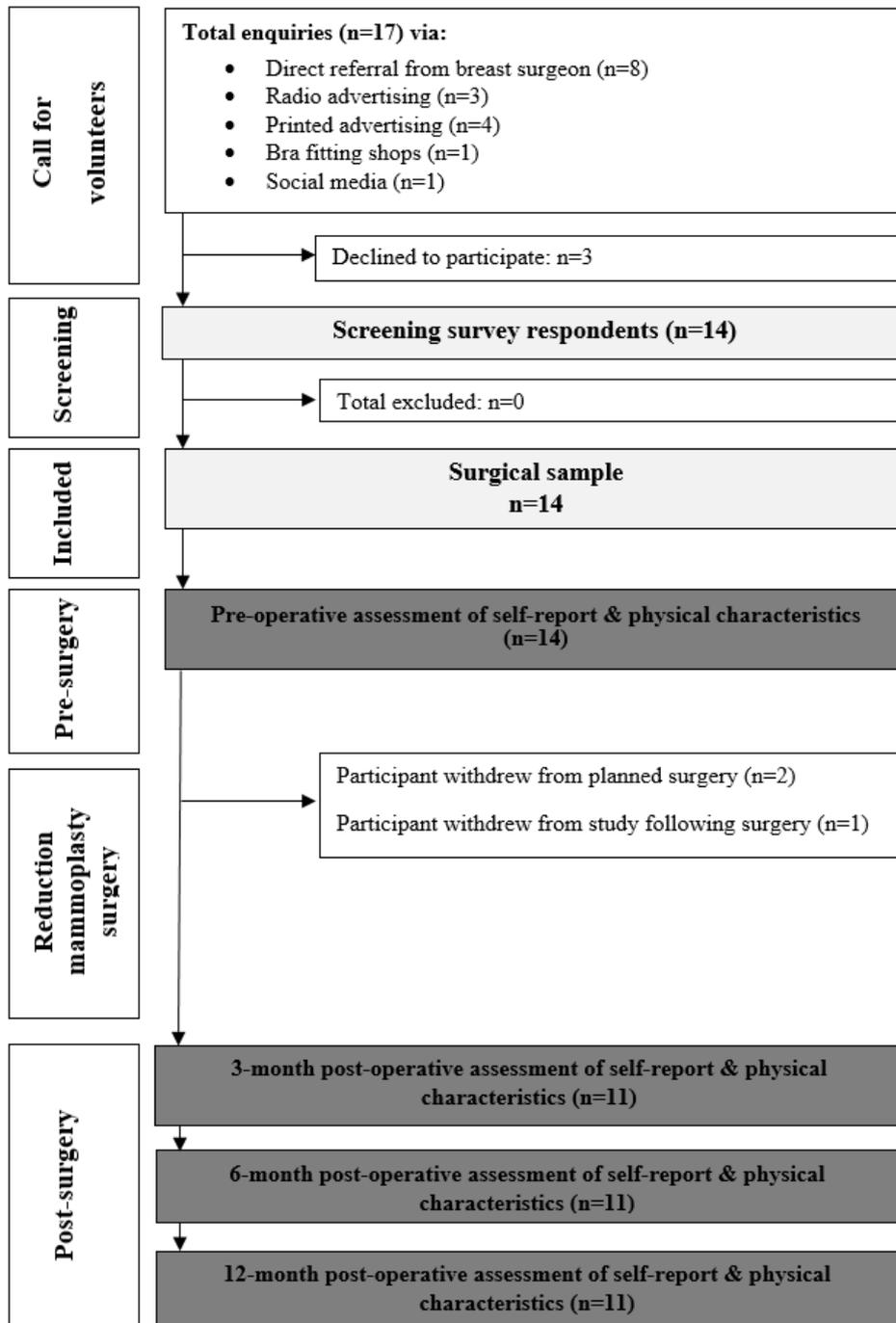
Figure 2.3 Study flow diagram: surgical sample

2.3   Procedures: self-report data collection

For the purposes of acquiring self-report data, an online survey platform (Qualtrics, version June 2016, Provo, Utah, USA) was used. The online survey was made accessible to participants electronically through the study website or via an emailed URL link. Those participants who did not have access electronically were provided with a hard copy of the

survey and participant informed consent form via post (n=2). The survey was an assimilation of a range of specifically designed questions (participant information questionnaire) (Appendix 4a) and standardised questionnaires (Table 2.1). These were principally selected on the basis of being most representative of the domain of interest but also having acceptable measurement accuracy, validity and reliability.

Table 2.1 Survey components

Variable (self-report characteristic)	Self-report measure	Community -based sample	Surgical sample
Participant characteristics			
Age (years)	PI questionnaire	●	●
Height (cm)		●	●
Weight (kg)		●	●
Menopausal status (pre/peri/post)		●	●
Employment status (FT/PT/nil)		●	●
Upper back pain			
Presence (yes/no)	PI questionnaire	●	●
Severity (NRS 0-10)	Numerical Rating Scale	●	●
Duration (weeks/months/years)	PI questionnaire	●	●
Breast size and breast and bra fit perceptions			
Bra size (band & cup)	PI questionnaire	●	●
Breast embarrassment (yes/no)		●	●
Desire to change breasts (yes/no)		●	●
Breast changes post-menopause (yes/no)		●	●
Bra professionally fitted (yes/no)		●	●
Bra fit satisfaction (yes/no)		●	●
Breast satisfaction (score 0-100)	Breast-Q (version 1.0 reduction module)	●	●
Physical activity			
Adjusted activity score (HAP AAS score 0-94)	Human Activity Profile	●	●
Health-related quality of life (generic)			
Physical component summary score (score 0-100)	Medical Outcomes Study Short-Form 36 Health Survey version 2.0 (SF-36)	●	●
Mental component summary score (score 0-100)		●	●
Health-related quality of life (specific)			
Breast-related psychosocial wellbeing (score 0-100)	BREAST-Q (version 1.0 reduction module)	●	●
Breast-related physical wellbeing (score 0-100)		●	●
Body satisfaction (NRS 0-10)	Numerical Rating Scale	●	●
Neck pain disability (score 0-50)	Neck Disability Index		●
Shoulder pain			
Presence (yes/no)	PI questionnaire		●
Severity (NRS 0-10)	Numerical Rating Scale		●
Pain chronicity (score 1-100)	Orebro Musculoskeletal Pain Screening Questionnaire (OMPSQ) short form		●
Surgical outcomes			
Breast satisfaction (score 1-100)	BREAST-Q (version 2.0 reduction module)		●
Satisfaction with nipples (score 1-100)			●
Satisfaction with outcome (score 1-100)			●
Satisfaction with information (score 1-100)			●
Breast-related psychosocial wellbeing (score 1-100)			●
Breast-related physical wellbeing (score 1-100)			●

● Measured characteristics. **Abbreviations:** PI questionnaire – participant information questionnaire; cm - Centimetres; kg - Kilograms; pre - Pre-menopausal; peri - Perimenopausal; post - Postmenopausal; FT - Full-time; PT - Part-time NRS - Numerical Rating Scale; HAP – Human Activity Profile; AAS – Adjusted activity score; SF-36 – Medical Outcomes Study Short-Form 36 Health Survey.

In consideration of responder burden, the length of time to complete the survey was planned not to exceed twenty minutes. Non-commercial licence agreements were sought free of charge for the use of standardised questionnaires where necessary. The online survey was designed to have a single continuous structure but, in accordance with the respective licence agreements, was inclusive of all instructions and preambles specific to each questionnaire. The order of questionnaires within the survey was planned to provide variety to the responder in the topics of question being asked and the type of response required (open versus closed response). Informed consent was obtained at the start of the survey in response to a statement that outlined the purpose of survey, expectations of the respondent and the option for anonymity (community-based sample only). Exclusion criteria were recorded in a question thereafter. On electronic versions, if a participant met one of the exclusion criteria, they were thanked for their contribution and were not able to progress further with the survey. Forced-response conditions were imposed on all questions of the electronic version to minimise missing data. The survey flow function on electronic versions of the survey allowed customisation of what a participant saw and which questions were asked based on the responses given. For example, if a participant reported that she did not have UBP, subsequent questions in the survey related to UBP severity and duration did not appear. All questions were presented in paper copies of the survey along with the option to select 'not applicable'. The community-based sample completed the survey on one occasion only. The surgical sample completed the survey prior to reduction mammoplasty and then again at three, six and twelve months postoperatively. Self-report data collected for each sample were identical with the exception of measures of neck pain, shoulder pain, pain chronicity and the outcomes of reduction mammoplasty. These extra measures were included only in the surgical sample to provide more in-depth information on the spectrum of disorders associated with larger breast sizes and how these change following surgery.

2.4   Self-report measures (both samples)

2.4.1   Measurement of participant's characteristics

The age, height and weight of participants in the community-based sample were captured in open questions. Self-report assessment of these characteristics were deemed to have acceptable validity given the sample size. Actual measures of these characteristics replaced the self-report values to improve validity in analyses of the postmenopausal subset. Menopausal status (pre/peri/post menopause) of participants was determined in a multiple choice question that provided definition to the respective statuses[148]. Employment status (full-time/part-time/nil employment) of participants was used primarily as a descriptor of the

sample. Where employment status was included as an independent variable in analyses, it was categorised dichotomously (employed or nil employment).

2.4.2 Measurement of upper back pain

In the absence of a widely used or validated measure of pain specific to the upper back, purposely-designed questions within the participant information questionnaire were used to assess aspects of UBP (Appendix 4a). Participants were provided with a body diagram where the upper back had been highlighted as the region above the base of the ribcage and below the neck. Using the diagram for reference, participants were asked if they had experienced pain in this region within the prior month (yes/no). A 1-month retrospective recall period was chosen as this has been previously advocated for studies investigating the prevalence of thoracic spine pain[2]. It is also a recall period included in standardised definitions of low back pain although here it is stated as '4-weeks' rather than 1-month[149]. The nature of UBP, sample characteristics, and the intention of the UBP measure were also considered prior to choosing this recall period[150]. The duration of time that participants had experienced UBP was assessed in a multiple-choice question that would allow categorisation of responses. The severity of UBP was assessed using an 11-point Numerical Rating Scale (NRS) of between 0 and 10 (0=no pain, 10= worst pain imaginable)[151]. A NRS score of ≤ 3 corresponds to mild, score of 4-6 to moderate and scores ≥ 7 to severe pain[152]. The NRS is a familiar and validated measure of pain severity that was chosen over other rating scales (e.g. VAS) because of its superior sensitivity and responsiveness[151, 153, 154]. The NRS was also easier to administer electronically and quicker to analyse. A minimum change score of 2-points on an 11-point NRS represents a minimal clinically important change (MCIC)[155].

2.4.3 Measurement of breast size and breast and bra fit perceptions

Bra size is commonly used to describe breast size and being familiar to most women makes it a suitable option as a self-report measure of breast size. Bra size is composed of a numerical band size and an alphabetical cup size. Cup sizes are not synonymous across band sizes which makes cup size alone an inadequate measure of breast size[156, 157]. Instead there is a sequential pattern associated with how cup sizes change with band size. Briefly, for each increment in band size, the cup size decreases by one alphabetical letter. In Australia for example, the average bra size is reported as a 14C which is equivalent to a 12D or 16B. For the measurement of breast size it is therefore important to consider both the band and cup size but, unfortunately, there can be small variations between styles of bras and between different bra brands (manufacturers)[141, 156]. Traditional bra sizing also does not provide a continuous measure of breast size for statistical purposes. As an option to address this, prior research has been done to convert bra sizes into equivalent breast volumes where breast

volume has been determined using 3D scanning and the water displacement methods[39, 157]. The volumes proposed reflect unilateral breast volume but to date, there has been large variability in the volumes that have been suggested for each bra size[39, 157]. It is difficult to be certain why there are not clearer trends between bra sizes and breast volumes but it could relate to the measurement accuracy of methods used to estimate breast volume[158], or indeed to the variability that may exist across bra sizes. Although breast volumes generally increase with bra sizes, in the absence of a more definite linear trend between these measures, it is seemingly unsuitable to interchange them.

A breast size score (BSS), derived from a participant's self-reported bra size is an alternative method for linearly ranking bra sizes to reflect breast size. The BSS method is based on a system used to size unilateral breast prostheses following mastectomy[159]. The BSS is an ordinal value (0-18) determined using numerical bra band sizes (size 8-24) and alphabetical cup sizes (AA-H) (Appendix 4b). The BSS increments follow a numeric pattern, increasing sequentially relative to bra sizes, providing it with face validity. A 1 cup size increase (e.g. C to D) on the same band size (under-bust e.g. size 12) is equivalent to a 1-point increase in BSS. Alternatively, a one band size increase (e.g. 12 to 14) with no change in cup size is also a 1-point increase in BSS. In the absence of an alternative measure for self-reported breast size, the BSS determined from bra size was chosen for use in this project. A modified version of the BSS method has been used in three previous studies[24, 26, 47].

Consideration was given to the potential errors that might have been introduced through subtle differences in BSS values determined from bras of different brands and also the possibility that women could be wearing, and would therefore report, a bra that was poorly-fitted and the incorrect size[24, 47, 141]. The preliminary work detailed in Chapter 4 allayed concerns over the magnitude of these potential errors. Further details on breast size measurement can be found in Chapter 4.

Closed questions in the participant information questionnaire asked whether a participant was embarrassed about their breasts, whether they would like to change their breasts, whether their breasts had changed following menopause (if applicable), whether they had their bra professionally fitted, and whether they were satisfied with their bra fit.

Breast satisfaction is a breast-related measure of body image. In the absence of a range of valid measures, breast satisfaction has previously been measured using combinations of closed questions and Likert scales that have been tailored to suit individual studies[28, 34, 160]. Patient reported outcome measures (PROMs) are widely used in breast surgical research to assess aspects of breast satisfaction. However, these PROMs often have a specific focus on

breast cancer or surgery outcomes[161]. The BREAST-Q[134] is a PROM that measures a range of breast-related themes including breast satisfaction, breast-related psychosocial wellbeing and breast-related physical wellbeing. Several modules of the BREAST-Q are available which vary according to the type of breast surgery being assessed. Irrespective of the module, the preoperative versions for each module, that acquire baseline information with no specific reference to surgery, can be administered at a single time-point in a cross-sectional survey to assess the breast-related themes[134, 162] (Appendix 4c). The breast satisfaction theme uses responses to 11 items that cover aspects of breast appearance clothed and unclothed to give a score of between 0 and 100 (higher scores indicating greater satisfaction). The BREAST-Q utilises specialised scoring software (Q-score, Mapi Research Trust, NY, USA) where all themes measured by BREAST-Q, can be scored as stand-alone scales. For the measurement of breast satisfaction, the BREAST-Q has demonstrated internal consistency (Cronbach's Alpha: 0.95), scale validity (interscale correlations: r=0.51), and reliability (Intraclass Correlation Coefficient (ICC): 0.84)[162]. These values supported its use in this doctoral research project. Whilst its validation and widespread use has predominantly been with women undergoing breast surgery, normative and pre-surgery data were available and suitable for comparison[163]. In the absence of established MCIC values, score changes in breast satisfaction are described as 'little' (5-10-points), 'moderate' (10-20-points) and 'very much' (>20-points)[164].

2.4.4   Measurement of physical activity

Self-report questionnaires are commonly used in place of direct methods in large epidemiological studies to provide a valid and reliable measure of physical activity levels[165]. Physical activity estimates are often higher when assessed with a self-report measure compared to direct methods[166], and this can result in self-reporting bias[167]. Self-report measures are, however, inexpensive and require no specialist equipment or face-to-face interaction which makes them more practical to use in studies with large sample sizes.

The Baecke and Modified Baecke Questionnaires are short assessments (maximum of 16-items) that are widely used with older adults for the assessment of physical activity in work, sports and leisure domains. Whilst they are quick to administer, produce a unit-less ordinal activity score and have acceptable validity and reliability[168], they were both considered to have limited content relevant to the participants of this project.

Providing more detailed and relevant content, the 94-item Human Activity Profile (HAP)[169] (Appendix 4e) was the selected alternative with good evidence of validity in adult populations[170]. The HAP produces an adjusted activity score (AAS) which represents a

participants typical daily activity level. The AAS can be presented as continuous data (0-94) or can be categorised. An AAS of less than 53 categorises a person as physically impaired, those with AAS in the range of 53 to74 are moderately active and those with AAS greater than 74 are categorised as very active[169]. Minimum detectable change scores of 6.8-points for AAS have been previously described and 14-points is an estimate of a MCIC[171].

2.4.5 Measurement of health-related quality of life

A measure of HRQoL can provide a holistic rating of personal, physical, and psychological aspects of health that might encompass the burden of any illness, injury, pain, or disability. The Medical Outcomes Study Short-Form 36 Health Survey (version 2.0) (SF-36)[133] is a generic HRQoL measurement tool that is widely used with people with low back pain[135, 136] and with a range of surgical patients, including women undergoing reduction mammoplasty[70, 74, 172]. Supporting its use in this project, the SF-36 version 2.0 has been validated through extensive psychometric testing[173-175] and normative data were available for comparison[133, 176]. The 36-item measure (Appendix 4f) comprises eight subscales and produces two summary scores. Item scores from the subscales of: physical functioning (10-items), social functioning (2-items), role limitations dues to physical problems (4-items), role limitations due to emotional problems (3-items), mental health (5-items), energy/vitality (4-items), bodily pain (2-items), and general health perceptions (5-items) are coded, summed and transformed to a scale of between 0 (worst possible health state) and 100 (best possible health state). Two standardised summary scores, the physical component summary (PCS) score, and the mental component summary (MCS) score, are calculated using the subscale scores[177]. Summary score changes of at least 5-points are considered above measurement error and indicative of a MCIC[178, 179].

A specific measure of HRQoL can be used to better characterise the burden of a particular condition[180]. Physical wellbeing and psychosocial wellbeing are two breast-related quality of life themes measured by BREAST-Q[134] (Appendix 4f). Physical wellbeing (14-items) captures the physical problems caused by breast size, including pain, rashes, energy levels, and sleeping problems. Psychosocial wellbeing (9-items) captures the emotional problems caused by breast size including effects on self-esteem, confidence in social settings, and perceptions of body image. Stand-alone scores of between 0 and 100 are generated for each theme, with higher scores indicating greater wellbeing. The validity and reliability of the BREAST-Q in evaluating these constructs has been previously reported to be good[162]. The BREAST-Q was chosen in this project as an allied measure to the SF-36 where it could provide particular insight into the specific burdens related to breast size. Preoperative data, presented in previous studies, were available for comparison[73, 76, 162, 181] and normative data

has been reported[163]. In the absence of a defined MCIC for physical and psychosocial wellbeing themes specific to the reduction module version used, a score change of 5-10-points was deemed 'a little', 10-20-points as 'a moderate', and greater than 20-points as 'very much' change[164]. These values were comparable to MCIC estimated on other modules of the BREAST-Q[182].

2.4.6 Measurement of body satisfaction

Body satisfaction can be considered as a dimension of body image that represents a subjective evaluation of body size and shape. A number of measurement scales are available to assess body satisfaction but many of these, such as the Body Dissatisfaction Scale[183] and Body Shape Questionnaire[184], relate specifically to the domain of eating disorders. Others, such as the Body Appreciation Scale[185] and Body Satisfaction Scale[186], whilst providing valid and reliable measures of body satisfaction, are lengthy and would have created an unrealistic responder time burden for the survey used in this project. A NRS of body satisfaction was instead included within the participant information questionnaire as a simple measure of body satisfaction (Appendix 4a). The NRS captured a single score of between 0 (completely unsatisfied) and 10 (completely satisfied) in response to the question "How satisfied are you with your body shape?" Similar numerical scales have been used in previous research on self-perceptions of mature (aged 45-65 years) women[28].

2.5 Self-report measures in surgical sample only

Self-report data that were additionally collected from the surgical sample included measures of neck pain disability, shoulder pain, pain chronicity, and surgery satisfaction outcomes. Neck and shoulder pain in addition to UBP are common physical complaints in women undergoing reduction mammoplasty[25, 26, 40] and are potentially important symptoms associated with larger breasts that have relevance to UBP. Pain chronicity, on the other hand, is a characteristic that has not been previously evaluated in women seeking reduction mammoplasty but which could be an important measurable aspect of the more general burden of larger breasts. Postoperative symptoms and satisfaction with surgery were measurable facets of the surgical experience with the potential to influence other outcomes. These were relevant to consider alongside the self-report and physical changes.

2.5.1 Measurement of neck pain disability

The Neck Disability Index (NDI) was used to measure disability associated with neck pain (Appendix 4g). The NDI is a 10-item multiple choice questionnaire that is widely used with people with chronic neck pain[187]. It quantifies the effect of neck pain on activities of daily

living by generating an overall score of between 0 (no activity limitations) and 50 (complete activity limitation). A 5-point change in the overall score on NDI represents a MCIC and its common use is in measuring change in neck pain over time[188, 189]. The NDI is a valid and reliable tool for this purpose[187, 188] and has normative data available for comparison[190]. In contrast to the Patient Specific Functional Scale[191] or Oswestry Disability Index[192], the NDI is a more specific measure of pain (and disability) felt in the neck.

2.5.2   Measurement of shoulder pain

A range of shoulder outcome measures were considered for the assessment of shoulder pain[193]. Many of these assess aspects of disability in addition to pain felt in the shoulder region and therefore provide more information than was required for the purposes of this project. An 11-point NRS was considered simple and sufficient to assess shoulder pain in the surgical sample (Appendix 4h). Within the participant information questionnaire, participants were provided with a reference diagram where the anterior and posterior aspect of each shoulder was highlighted. Pain experienced in these regions was rated by participants between 0 (no pain) and 10 (worst pain imaginable). Scores on the NRS can be categorised as mild (≤ 3-points), moderate (4-6-points) or severe (≥ 7-points)[152] and a change score of 2-points on the NRS was considered a MCIC[155].

2.5.3   Measurement of pain chronicity

The Orebro Musculoskeletal Pain Screening Questionnaire (OMPSQ) (short-form) (Appendix 4i) was used to assess the risk of pain chronicity. The OMPSQ is a widely-used and validated instrument for predicting chronic pain, perceived mental health and functional disability[194, 195]. Answers given in response to this 10-item questionnaire generate a score of between 1 and 100 with higher scores indicative of greater estimated risk of chronicity and disability. The reasons for selecting this tool included its widespread clinical use and the large amount of available comparative data, in addition to its simplicity and its applicability to pain felt in regions other than the lower back. Scores of 50 or above indicate those people at greater risk of chronicity[195]. Using this criterion, this tool was employed as a screening measure of pain chronicity in the surgical sample preoperatively and compared to scores attained postoperatively.

2.5.4   Measurement of surgical outcomes

In addition to the themes of breast satisfaction, breast-related physical wellbeing and breast-related psychosocial wellbeing measured by BREAST-Q that have already been described, the BREAST-Q also has the capability to measure additional themes relevant to the outcomes of reduction mammoplasty[196]. Using the BREAST-Q Reduction/Mastopexy

postoperative version 2.0 (Appendix 4d), satisfaction with nipples (5-items) satisfaction with outcome (8-items) and satisfaction with information (13-items) were themes that were evaluated in the surgical sample at three, six and 12-months post-surgery. Scores on each scale of between 0 (completely unsatisfied) and 100 (completely satisfied) indicate the level of satisfaction. The BREAST-Q has been frequently used in breast surgical research[181] and the multi-purpose use of BREAST-Q in this project supported its selection for the measurement of pre-to-post-surgery changes in the surgical sample.

2.6 Procedures: objective data

For the purposes of assessing the physical characteristics of the postmenopausal subset and surgical sample, objective measures were undertaken in a clinical setting. Participants attended Curtin University Health and Wellness Centre to complete a protocol of measures that lasted less than 60 minutes (Table 2.2). The order of tests within the protocol was standardised and carefully considered to minimise fatigue of the participant and delays associated with participants dressing and undressing. The setting for completing the protocol was a secure treatment room within the Health and Wellness Centre. The ambient temperature of the room was consistent with the rest of the centre. All procedures were undertaken in this room with the exception of the measurement of BMD, which occurred in an adjacent room containing specialist equipment, and radiographic measurement of thoracic kyphosis, which occurred offsite at community-based radiological clinics (refer to section 2.7.8).

Table 2.2 Protocol of objective measures

Order	Variable (physical characteristic)	Objective method
1	**Anthropometry**	
	height (cm)	Stadiometer
	weight(kg)	Calibrated scales
	body mass index (kg/m²)	Calculator
2	**Bone mineral density (BMD)**	
	BMD lumbar spine L2-4 (g/cm²)	Dual energy X-ray absorptiometry
	BMD left and right femoral neck (g/cm²)	
3	**Body composition**	
	Lean mass (kg)	Dual energy X-ray absorptiometry
	Fat mass (kg)	
4	**Breast characteristics**	
	Breast size (BSS)	Tape measure
	Breast ptosis (cm)	Tape measure
	Breast splay (cm)	Tape measure
5	**Upper back extensor muscle endurance** (s)	Isometric chest raise test
6	**Bra fit** (pass/fail)	Professional bra fitting criteria
7	**Thoracic kyphosis**	
	Non-radiological thoracic kyphosis (°)	Flexicurve
	Radiographic thoracic kyphosis (°)[a]	Plain X-ray
-	**Thoracic spine morphology[a]**	
	Vertebral fractures (total number)	Plain X-ray
	Thoracic intervertebral joint osteoarthritis (mild/moderate/severe)	
8	**Posture**	
	Head posture (craniovertebral angle) (°)	Photogrammetry
	Upper back posture (cervicothoracic angle) (°)	
	Shoulder posture (shoulder protraction angle) (°)	
9	**Upper back mobility**	
	Thoracic extension range of movement (°)	Photogrammetry
10	**Upper back musculoskeletal tissue sensitivity**	
	Pressure pan thresholds (kPa)	Digital algometry

[a] Assessment completed off site. **Abbreviations:** cm - Centimeters; kg - Kilograms; kg/m²- Kilograms per metre-squared; g/cm² – Gram per centimeter-squared; s - Seconds; BSS - Breast size score; kPa – Kilopascals

2.7 Objective measures

2.7.1 Measurement of anthropometry

Height and weight were measured using a stadiometer (Seca 222, Seca, Hamburg, Germany) and digital scales (EB9300, Camry, China) respectively. Body mass index (BMI) (kg/m²) was calculated by dividing weight (kg) by height (m) squared.

2.7.2 Measurement of bone mineral density

Bone mineral density is a measure of minerals contained within a certain volume of bone and is used as a clinical indicator of fracture risk and in the diagnosis of osteoporosis[197]. The gold standard measurement technique for BMD is dual-energy X-ray absorptiometry (DXA) which uses high and low energy photons to discern different body tissues based on their variable absorption of X-rays[198]. It has a high reported accuracy and low margin of error[199]. In addition to its measurement precision, the use of DXA is fast (short scan times of 2-3

mins), requires minimal set-up, and is associated with a low radiation dose[200]. A DXA scanner (Lunar Prodigy, GE Healthcare Little Chalfont, UK) located onsite at the Curtin Health and Wellness Centre was used to measure BMD in participants. With access to a DXA scanner onsite and without cost, no alternative methods were considered. As a prerequisite of its use, a radiation safety course was completed by the thesis candidate in addition to 10 hours of practice using the scanner. A radiation monitoring badge worn by the thesis candidate during scanner operation times detected and measured radiation exposure.

Central and axial DXA examinations, that evaluated the BMD of the lumbar spine and hip respectively, were used in this project[198]. Estimated radiation dose, approved by the Curtin University Radiation Safety Advisor were 0.7uSv and 0.68uSv for lumbar spine and hip respectively. All participants wore their underwear and an open-backed gown and underwent both scans providing that no prosthetic material was in situ in either body region (e.g. total hip replacement). Quality assurance tests were routinely completed prior to use which included calibration measurement using a phantom spine. For the lumbar spine examination, participants were positioned in supine with their arms at their sides and legs raised on a box with their knees bent to neutralize the curve of the lumbar spine. For hip examinations, participants were positioned supine with their hips abducted to approximately $25°$ and fully internally rotated. A triangular splint with adjustable Velcro straps positioned in-between the lower legs assisted participants to maintain this position. The scans provided a measure of BMD (g/cm^2) at the lumbar spine (L2-4) and at the FN in both hips. Average values between the left and right FN were used as the measure of BMD. In addition, T-scores obtained at the left FN were used to identify those participants with osteoporosis (T-score<-2.5)[197]. A T-score reflects the difference in number of standard deviations between the mean measured BMD and that of a young healthy adult and is the common unit of measurement for BMD used in established definitions of osteoporosis by the World Health Organisation[201]. Participants were issued with a copy of their results and notified in writing if they had low BMD (FN T-score <1.0)[202].

The potential sources of error associated with DXA scans that were important to monitor included the possible distorted analysis of BMD in participants with degenerative disease[203], errors associated with scanning technique (subject positioning and movement), and errors associated with artefacts (foreign bodies or bone disease)[198]. All scans were checked for accuracy immediately following acquisition and later verified by a study supervisor with over 25 years' experience using DXA.

2.7.3 Measurement of body composition

Dual-energy X-ray absorptiometry was also employed in this project as a tool for measuring body composition. Compared to alternative anthropometric measures used to assess body composition (e.g. skin fold thickness, waist circumference, waist-to-hip ratio), DXA provides a greater level of measurement accuracy[199] and is less time-consuming to complete. As the gold standard assessment method for body composition assessment, DXA has been used widely in prior research, particularly in the topical areas of eating disorders[204] and body weight management[205]. A whole body scan of 6-11 minutes duration, depending on body size, with participants positioned in supine, provided a measure of total fat and lean mass. For the purposes of this project these were both expressed in kilograms (kg). Radiation doses for a participant of typical size undergoing this scan were estimated and approved by the Curtin University Radiation Safety Advisor as 0.50uSv.

2.7.4 Measurement of breast characteristics

Breast size is a poorly defined term with no agreed gold standard objective method of assessment other than measuring resected breast tissue after mastectomy. Breasts can be described according to bra size or be quantified by shape, volume or density. In section 2.4.3, bra size was described as a common and familiar measure of breast size that could be self-reported. Measuring a woman for bra size is a versatile method that can also be objectively determined[206]. Breast volume however, is the most commonly-used objective measure of breast size[37, 207-209]. A range of breast volume measurement techniques are available which vary in complexity, accuracy and cost. The anthropometric and Grossman-Roudner cone are simple and efficient methods, the water displacement and thermoplastic casting methods are more time-consuming and the scanning methods of mammography, 3D and MRI are expensive and require specialist equipment[36, 37, 210-215]. The difficulties of measuring breast volume are well-acknowledged[36-39] and it is not clear that more sophisticated and expensive methods are more accurate[36]. In addition some methods are not well-tolerated by women[37]. As irregular, asymmetrical and dependent anatomical features, the volumes of breasts are difficult to estimate because they are hard to define geometrically and are influenced by gravity. This is particularly problematic when measuring large ptotic breasts[39, 54, 216]. Measurement techniques that required specialist equipment and that were not considered for use in this project included mammography, MRI, thermoplastic casting, and 3D scanning. The costs associated with these methods prohibited their use. The gold standard method, mastectomy specimen weight was not considered for this project. Techniques such as the water displacement method and Grossman-Roudner cone, that are time consuming and not well-tolerated by participants[37, 38, 217] were also ruled out. The

43

anthropometric method was considered for estimating breast volume and the practicability of this method was examined in preliminary work of the project (Chapter 4). The large potential for errors in estimating breast volume using the anthropometric method was a concern. These errors were particularly highlighted in women with ptotic breasts (refer to Chapter 4).

The use of measured bra size for estimating breast volume was also considered but, with previous evidence demonstrating that large volume ranges were possible for each bra size, there was some doubt over the accuracy of this method[39, 57, 157]. A bra size of 12D, for example, is estimated to have volumetric equivalent of between 350-699ml[157]. The large volume ranges per bra size clearly suggests that there could be sizeable margins of error in estimating breast volumes from bra size and this seems more likely as in women with larger bra/breast sizes[39].

Following the preliminary work outlined in Chapter 4 an objective measure of bra size that was converted into an ordinal BSS was chosen for the measurement of breast size. In addition to its simplicity, this efficient measure was reliable and complemented the self-report measure of breast size employed in the project.

A BSS determined by objectively measuring a woman for bra size (band and cup size) requires the measurement of under-bust and over-bust circumferences. A length measured in centimeters and rounded to the nearest millimeter, taken with a tape measure placed firmly against the chest under the breasts and horizontally level around the back provides an under-bust circumference. A measure taken with the tape measure placed firmly against the chest level with the nipple line and horizontally level around the back provides an over-bust circumference. Since respiratory state can affect these circumferential measurements it is suggested that they are taken from participants at the end of expiration[156]. Using a conversion chart (Appendix 4b) based on those produced by a bra manufacturer[218], these circumferential measures were then converted into a BSS. With use in previous research[39, 157], and providing the greatest range of bra sizes, the circumferential ranges used in the Berlei bra fitting chart[218] (https://www.berlei.com.au/size-charts) were incorporated into the BSS conversion chart specifically developed for this project (Appendix 4b). A BSS of between 0-18 was determined by selecting the under-bust circumference measurement in the horizontal boxes at the top of the chart and then finding the over-bust circumference measurement in the column of boxes below. Each box ascribes an ordinal BSS based on the sequential pattern of bra sizes/circumferential measures that is similar to that used in the sizing of unilateral breast prostheses[159]. Refer to Chapter 4 for further details on breast size measurement.

Breast ptosis describes the position of the nipple in relation to the inframammary fold. This has traditionally been graded on a descriptive scale (nil to major)[221]. A quantitative measure of breast ptosis can be taken from fiducial points of the breasts captured by photography[222] or, more simply, by measuring of the distance between the sternal notch and nipple[223]. The latter method provides continuous data, is quicker to use and is less subjective. For these reasons the sternal notch-to-nipple distance was chosen as a measure of breast ptosis. These measures were taken with participants in a sitting position with their hands on their hips.

Breast splay describes the distance between the left and right nipples and is measured using a tape measure with participants in sitting[223]. Normative data for breast ptosis and breast splay across women of varied age were available for comparison[210, 223, 224].

2.7.5 Measurement of bra fit

Professional bra fitting criteria have emerged as the most accurate method for assessing bra fit[54, 141, 143, 225]. The criteria evaluate the band, cup, underwire, straps and front brand of a bra to produce an overall rating of pass or fail[141] (Appendix 5b). For a bra to achieve a pass rating, the band must be neither too tight nor too loose. Flesh should not bulge over the top of the band and a bra should not move when arms are elevated. The cup of a bra should be a sufficient size to fit the breast. Breast tissue should not bulge out of the cup nor should the fabric of the cup be crinkled indicating it is too large. The underwire of a bra should be the correct shape and should not sit on the breast tissue laterally or feel uncomfortable. The straps of a bra should not dig into the skin over the crest of the shoulder, nor be too loose, and slide off the shoulders. The front band of a bra should be in contact with the sternum and should not move when the arms are lifted. The checklist format of these criteria are simple and efficient to use in a clinical setting and for this reason they were included in this project to evaluate if a participant was wearing a correctly fitted bra.

2.7.6 Measurement of upper back extensor muscle endurance

Several methods to quantify upper back extensor muscle endurance were considered. These ranged from surface electromyography and dynamometric tests which use specialised equipment, to more conventional timed physical tests that use little equipment[226]. The choice of assessment tool for upper back extensor muscle endurance was strongly influenced by the facilities and equipment available for repeated and regular use with a large sample, the practicability of the tool when used in a clinical setting with people with UBP, and the burden to participants in terms of time. As a result of these considerations, the isometric chest raise test was chosen.

The isometric chest raise test (Figure 2.4) is an adapted version of the widely-used Sorensen test, the most commonly used and studied test for assessing spine extensor muscle function[227, 228]. The isometric chest raise test uses subtle methodological variations of the Sorensen test to isolate the assessment of upper back extensor musculature[115, 229, 230]. The test requires participants, from a prone position with a cushion under the abdomen, to lift their chest clear of support by extending their upper back[115, 230]. Endurance is quantified as the length of time (s), to volitional fatigue, that the participant can hold this position. A hold-time of a time of ≥160s places women aged over 50 years above the 75th percentile in relation to age-referenced norms[115]. The isometric chest raise test has previously been reported to have high reliability (ICC 0.93-0.97) and reproducibility (r=0.94-0.9.5) when used with women (aged 35-49 years) with and without chronic back pain[230].

Figure 2.4 The isometric chest raise test

A number of methodological issues were considered to optimise the valid and reliable use of the isometric chest raise test in the project. Firstly, the specificity of body position during set-up was essential to produce a valid test. It was important to standardise the pivot point of the upper back by defining the umbilicus as the point above which extension would occur. Secondly, it was important to limit hip and lower back extensor muscle activation through the appropriate placement of holding straps (Figure 2.4). Thirdly, it was necessary to ensure sufficient clearance under the chests of participants with larger breasts so that the start and end point of the test could be clearly defined. This was addressed using a wedge cushion (Lunamumma, VIC, Australia) with a larger (24cm) edge, as opposed to a flat cushion, under the abdomen. The wedge cushion also helped to position participants so that they would not be impeded if their extension mobility, beyond neutral, was poor. Finally, the termination criteria for the test had to be defined. Volitional fatigue was defined as the point at which the chest touched the bed. Participants who could not lift the chest from the bed to initiate the test were allocated a time of zero seconds. In consideration of the time constraints for the

protocol, an upper limit cut-off time of 300-seconds was imposed. A time of 300-seconds has been used previously as an appropriate criterion for terminating the test[230]. A hold time of 300-seconds is above the 75th percentile of referenced norms for performance of this test by women aged >40 years[115] and this confirmed it to be a suitable termination point.

As with other measures of endurance, the isometric chest raise test could be potentially influenced by several confounding factors[231]. All human endurance measurements are subject to motivational influences. The results could be compromised if the participants failed to offer full effort to the point of fatigue and could also be affected by participant competitiveness and pain tolerance. To address these points, standardised instructions for the safe performance of the test to self-defined limits of pain and fatigue were utilised (Appendix 5a). Participants were encouraged to produce their best effort in the standardised preamble but were not encouraged verbally following the start of the test. The results of other participants were not disclosed.

2.7.7 Measurement of upper back mobility

Goniometer, inclinometers and photographic methods were considered for the assessment of thoracic spine extension range of movement (upper back mobility). The photographic method previously validated by Edmondston et al[100] and described in full in Chapter 3, section 3.7.1 was chosen for its accuracy and speed. This method involves the acquisition of two lateral photographs of participants in two positions (rest and maximal thoracic extension) (Figure 2.5). Photo-reflective markers placed on the spinous processes of T1, T4, T8 and T12 provide reference points for the calculation of the thoracic angle at rest and in maximal thoracic extension using a digitisation process. The difference in degrees between these angles is used to determine thoracic extension range of movement.
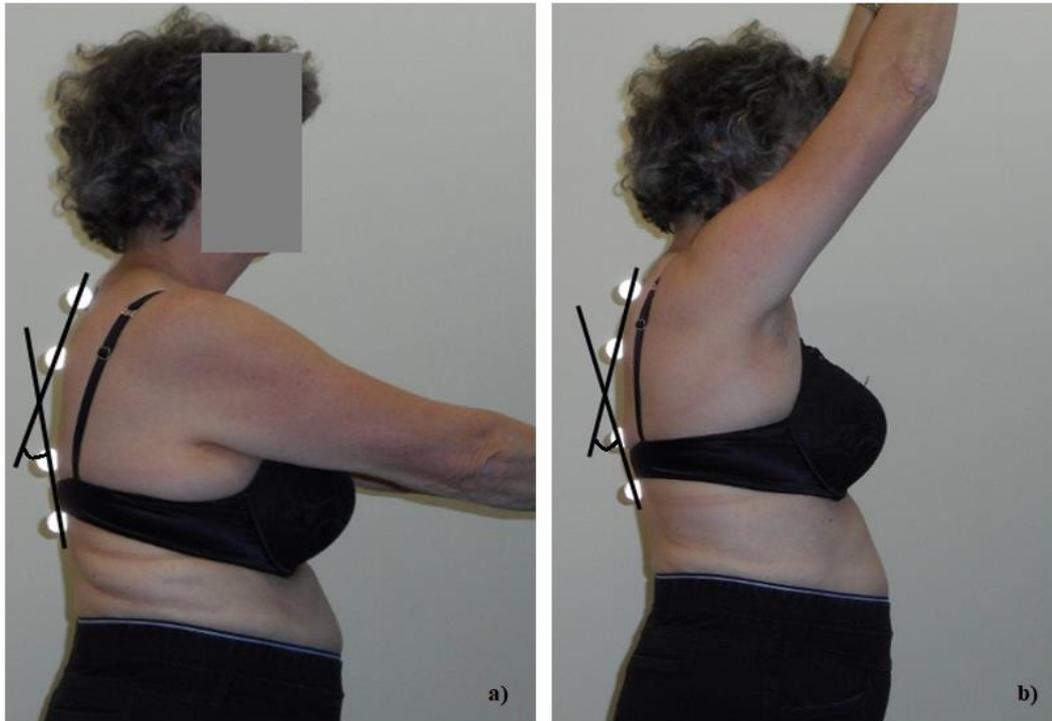
Figure 2.5 Assessment of upper back mobility using the photogrammetry **a)** rest position and **b)** maximal thoracic extension

This method provides an accurate estimation of thoracic extension range of movement compared to gold standard radiographic methods (r=0.69), and has been used reliably by physiotherapists in the past (standard error of measurement, SEM: 0.6°)[100, 101]. The preliminary work of this project established the reliability of the digitisation method used to measure upper back mobility angles (refer to Chapter 3) which was important in a project where repeated measures were being employed (surgical sample).

Normative data for thoracic extension range of movement show some variation which may be partly attributed to differences in measurement methods. In asymptomatic women aged between 50-75 years for example, thoracic extension range of 13° (±8°) has been reported using goniometry[232]. Lower ranges of thoracic extension (0.9°to 3.9°) have been recorded in a more diverse sample aged 27-81 years (including male and females) with cervical and lumbar spinal disease where movement was measured between individual thoracic segments using computed tomography[233]. Using the photographic method described above, thoracic extension ranges of motion of between 8° and 23° have been recorded in one group of young asymptomatic men[100] and with a mean (SD) of 12.8±7.6° in another similar group of men[101]. We may expect photographically-measured angles in women of middle and older age to be less than this, with age clearly identified as a factor that influences thoracic extension range of movement[232, 233].

2.7.8   Measurement of thoracic kyphosis

Thoracic kyphosis is the primary curve of the spine from T1-T12 in the sagittal plane. Radiographic angles measured from lateral radiographs of the thoracic spine are widely-accepted as the gold standard measurement methods for thoracic kyphosis. The Cobb angle is the angle formed by perpendicular lines that extend from reference lines drawn through the superior endplate of T1 and inferior endplate of T12 (Figure 2.6a)[234]. The vertebral centroid angle uses reference lines that intersect the centre of the two upper most vertebrae (T1-T2) and two lower most vertebrae (T11-T12) (Figure 2.6b)[235]. In older populations, where degenerative change can affect vertebral endplates and distort Cobb angles, the vertebral centroid method is advocated for use in assessing thoracic kyphosis[236].
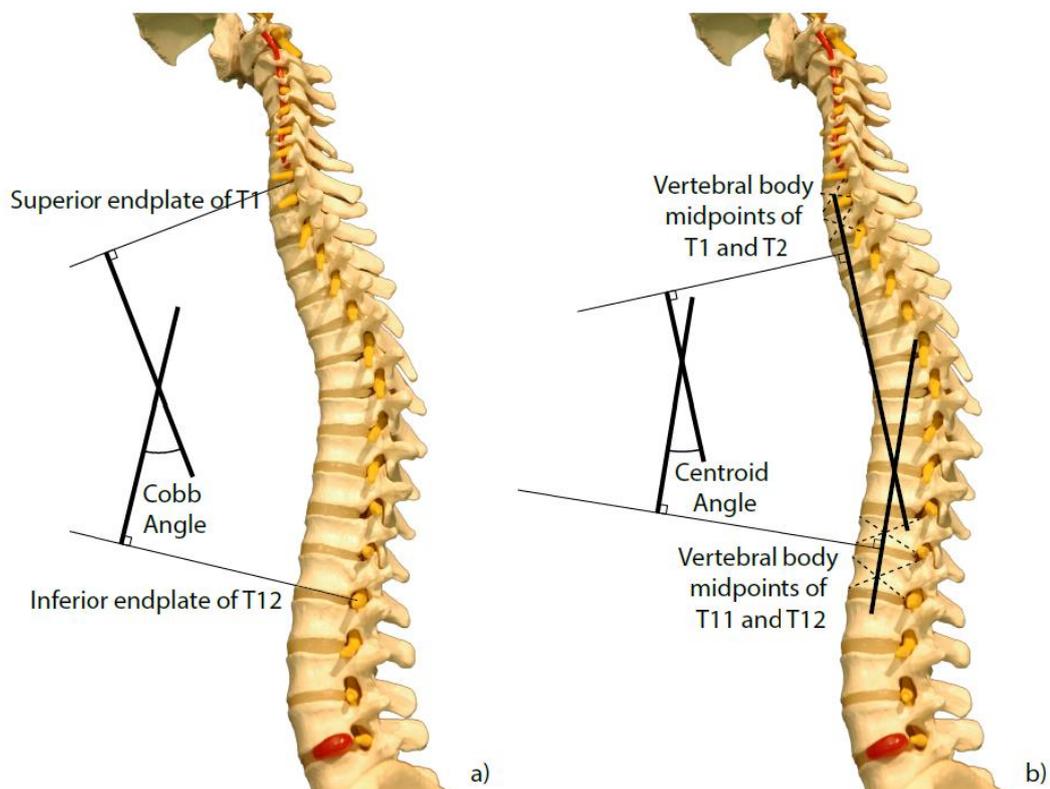
Figure 2.6 Radiographic thoracic kyphosis angles: a) Cobb angle and b) vertebral centroid angle

A range of non-radiological options are also available for the estimation of thoracic kyphosis[62]. Flexicurve (Figure 2.7), a plastic coated flexible lead ruler (Fabell-Castell, Germany) is a popular and reliable non-radiological tool with strong correlation to the radiographic Cobb angle method[59, 61, 63, 64, 237].

Figure 2.7 The Flexicurve

Flexicurve is contoured to the shape of the spine between C7 and S2 and then the outline is traced onto paper where specific dimensions are measured (Figure 2.8). These include the thoracic width (TW), which is the apex of the kyphosis curve, and the vertical length above this to C7 (L1), and below this to the end of the thoracic length (L2). A mathematical formula (TK = arctan (TW/L1) + arctan (TW/L2) is then used to determine a Flexicurve kyphosis angle using these dimensions[59]. Whilst being simple and fast to use, Flexicurve commonly underestimates radiographic Cobb angles which has cast some doubt over its validity[59, 61, 64, 237].
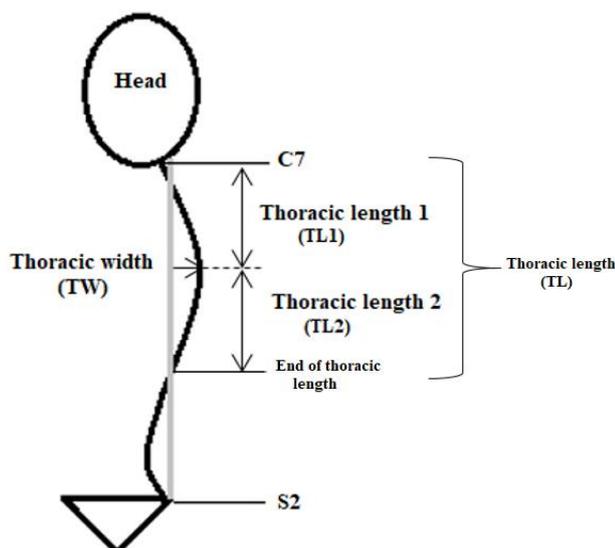
Figure 2.8 Flexicurve kyphosis angle. Dimensions used in Flexicurve kyphosis angle calculation (Thoracic kyphosis = arctan (thoracic width (TW)/thoracic length 1 (TL1) + arctan (thoracic width (TW) /thoracic length 2 (TL2)[59]

In deciding which specific measure to use, the accuracy, cost, and radiation exposure were considered. Following an agreement with a community-based radiological imaging company, radiographic methods were chosen for the measurement of thoracic kyphosis. With over 20 clinics in the Perth metropolitan area participants were able to choose a convenient site to undergo their X-ray assessment as part of the agreement with the Perth Radiological Clinic group. A single lateral thoracic X-ray of each participant was planned that, for a typical participant size, would deliver 0.3mSv. Participants were referred for an X-ray following completion of all other measures. Standardised instructions written on the referral for radiographers were to take a single right-sided lateral thoracic X-ray with the participant's arms flexed to 90°. The X-ray device was to be positioned at a film focus distance of 120cm with the beam centered on the mid thoracic vertebrae. Radiological equipment across clinics was similar and one consultant radiologist, blinded to the aims of the project, agreed to analyse all X-rays.

Without adding excess time to the protocol, Flexicurve was included in the measurement protocol and was initially proposed as a back-up measure of thoracic kyphosis for participants who were unable, or unwilling, to undergo an X-ray examination. However, with questions over the validity of Flexicurve raised in a recent small study[64], it was of interest to also explore its validity in measuring thoracic kyphosis in postmenopausal women. This work was completed in view of the potential importance of thoracic kyphosis as a keystone of biomechanical theories linking breast size to UBP (refer to section 1.3.7) and is detailed in full in Chapter 5.

2.7.9   Measurement of thoracic spine morphology (vertebral fractures and osteoarthritis)

From the lateral X-ray used in the assessment of thoracic kyphosis, thoracic vertebral fractures and thoracic intervertebral joint osteoarthritis were identified. Radiographic methods are widely considered the gold standard for the assessment of these characteristics[238-241]. Prevalent vertebral fractures were identified as those vertebrae with a 20% reduction in vertebral body height relative to normal adjacent vertebrae using a semi-quantitative method[239]. In accordance with normal clinical practice, osteoarthritis was descriptively assessed as 'mild', 'moderate' or 'severe' by the consultant radiologist using clinical judgement of the whole thoracic spine.

2.7.10   Measurement of posture

Methods considered for the measurement of body posture included goniometers, inclinometers and photography[60]. Three upper body postures were of interest in this project (Figure 2.9): head posture (craniovertebral angle)[242], upper back posture (cervicothoracic angle)[243], and shoulder posture (shoulder protraction angle)[244]. The photographic method was chosen because it was able to measure all of these angles in a comparatively short time compared to other methods. The methodology, outlined in detail in the reliability study presented in Chapter 3, was employed to measure all three posture angles. Using the photographic method, posture angles were estimated from a single lateral photograph of participants. Prior to acquiring the image, photo-reflective markers were fixed to specific anatomical landmarks (refer to section 3.7.1). Once captured, images were digitised using an image processes software (ImageJ, National Institutes of Health, Bethesda, MD). Angles formed between relevant photo-reflective markers were then digitally measured (Figure 2.9). The craniovertebral angle was the angle formed between a line drawn from the tragus of the ear to the seventh cervical vertebrae subtended to the horizontal[244]. A smaller craniovertebral angle indicates a more forward head posture and with reverse scaling of the normative data, produced by Raine and Twomey[244], an angle >48.9° may be considered normal. The cervicothoracic angle was the angle between a horizontal line and a line between the seventh cervical and seventh thoracic vertebrae[243]. A larger cervicothoracic angle indicates a more rounded upper back posture and angles that vary between 107-127° for asymptomatic individuals (n=30) and between 114-135° in individuals with neck pain (n=30)[245] have been previously reported. The shoulder protraction angle was formed between a horizontal line and a line between the mid-point of the shoulder and C7. A smaller shoulder protraction angle indicates a more protracted (rounded) position of the shoulder and normative angles of 47.6° (10.4°) have been previously reported in young adults (mean age 22 years)[242].

In prior research, some variation has been noted in the angles measured from the same person, particularly for head posture, between the positions of sitting and standing[246] suggesting that there could be positional influences on posture angles. As part of the preliminary work of the project, the reliability study also established the variability in angles between the positions of sitting and standing, before deciding on standing as the position from which angles would be measured (refer to Chapter 3). This preliminary work also determined that the thesis candidate was reliable in digitising photographic posture angles. Validation against gold standard radiographic methods for shoulder and craniovertebral angles has also been reported as good[247].
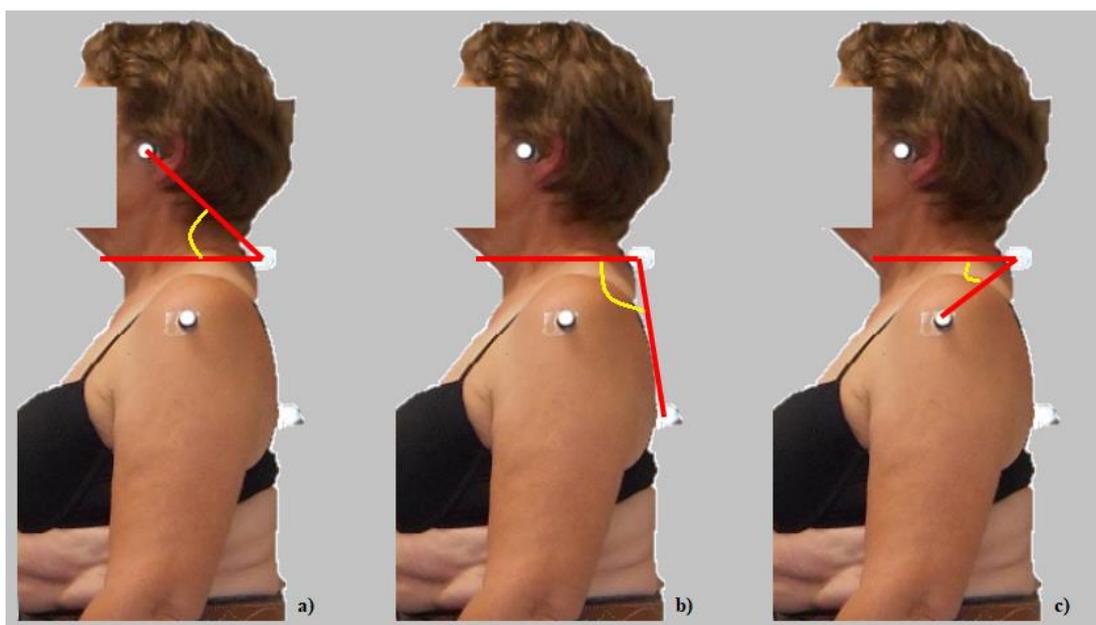
Figure 2.9 Posture angles assessed using photogrammetry: **a)** head posture (craniovertebral angle), **b)** upper back posture (cervicothoracic angle) and **c)** shoulder posture (shoulder protraction angle)

2.7.11 Measurement of upper back musculoskeletal tissue sensitivity

Musculoskeletal tissue sensitivity was objectively assessed using pressure pain thresholds (PPTs)[248]. In a Maitland-based approach, central PA applied pressures[249] used in prior research as thoracic spine pain provocation tests[24] were also considered for the purpose of giving a quantitative region-specific measure of vertebral sensitivity. Pressure pain thresholds are determined using a digital algometer, where the controlled application of pressure using a probe directly against a body tissue at a constant rate, records the minimum amount of pressure that induces pain or tenderness[248]. In contrast to the Maitland assessment technique, algometry provides a quantitative measure of tissue sensitivity and can be used on both skeletal and muscular tissues. Algometry was chosen because of these advantages but

also because of the strength of evidence supporting its reliability (ICCs>0.81) and repeatability (ICCs>0.86) in quantifying local tissue sensitivity[250, 251]. Studies investigating the reliability of PPT using algometry have used a variety of body regions[250-252] and protocols[253]. Most reliability studies have been conducted using asymptomatic participants and normative data for some tissues in the upper back are available[248, 252, 254]. Pressure pain thresholds measured in these studies show large normal regional variation within the body with some tissues showing greater sensitivity than others.

For the purposes of this project, six skeletal sites (spinous processes of T2, T4, T6, T8, T10 and T12) and six muscular sites (levator scapulae, pectoralis minor, sternocleidomastoid, upper trapezius, middle trapezius, and lower trapezius) were chosen for assessment. Descriptive accounts of the potential strain on these tissues in women with large breasts informed the decision to assess these sites[27]. The methodology outlined in detail in section 3.7.2 was employed. An averaged PPT taken over three trials on each site were used. Standardised procedures, including the rate of pressure application, participant positioning, and participant instruction (Appendix 5a) were used and randomisation of the testing order minimised carry-over effects of repeated measurement at each site. Preliminary work allowed familiarisation with the equipment and determined that testing at each anatomical site was practical and tolerable for participants. This work also established that digital algometry was reliable in measuring PPT at upper back sites when used by the thesis candidate (refer to Chapter 3).

2.8   Thesis plan

Following Chapters 3 to 5, which outline work on specific measurement procedures, the chapters of this hybrid thesis are arranged to sequentially address the research questions outlined in section 1.6.

Chapter 3 outlines the preliminary work that was conducted to establish the reliability of methods planned for assessing posture, upper back mobility and upper back musculoskeletal sensitivity. The chapter describes the measures chosen for the assessment of these physical characteristics and provides estimates of intra-rater reliability to support their use.

The measurement of breast size was a crucial component of this thesis. Chapter 4 outlines the challenges associated with measuring breast size accurately and the range of methods that were considered feasible. Preliminary work undertaken with the aim of selecting one suitable self-report and one suitable objective measure of breast size, is described.

Chapter 5 describes, by way of published paper[255a], the rationale for choosing a radiological method for assessing thoracic kyphosis in postmenopausal women. The evidence presented in this chapter provides clear support for the use of radiographically-measured thoracic kyphosis angles as opposed to thoracic kyphosis angles calculated non-radiologically using the Flexicurve ruler.

In an exploratory approach, Chapter 6 describes, by way of published paper[255b], aspects of health and psychological wellbeing in mature-aged women (community-based sample) that are associated with breast size. As part of this exploration, breast size is initially examined as an associated risk factor for UBP. The role of age, BMI and menopausal status are also considered as factors relative to breast size with the potential to influence aspects of health and psychological wellbeing.

Chapter 7 is a supporting chapter, building on the findings regarding breast size and UBP from Chapter 6 that examines aspects of health and psychological wellbeing that are associated with UBP. In a re-examination of the same community-based sample dataset, consideration is given to those self-reported health and psychological wellbeing characteristics that, independent of breast size, are associated with the presence and severity of UBP. The chapter describes the multidimensional nature of UBP and the implications of this for examining breast size as a related factor.

Chapter 8 describes, by way of published paper[256a] the physical characteristics associated with the presence and severity of UBP in postmenopausal women (postmenopausal subset). This chapter collectively examines a large number of physical characteristics in relation to UBP and considers those most likely to increase the likelihood and severity of UBP. Breast size is explored as a physical characteristic whose relative importance to others is investigated.

In a re-examination of the postmenopausal subset, the physical characteristics associated with breast size in postmenopausal women are appraised in Chapter 9. This supporting chapter focuses on those physical characteristics that are considered anecdotally, or by prior investigation, to be relevant to explaining the relationship between breast size and UBP. Chapter 9 explores those physical characteristics that breast size has the strongest relationship with and discusses the implications of these relationships in the context of UBP.

Chapter 10 describes, by way of published paper[256b], the relationship between breast size and prevalent thoracic vertebral fracture. In an examination of the postmenopausal women, this chapter explores breast size as a novel associated risk factor for prevalent vertebral fractures. The biomechanical rationale for a relationship between increasing breast and vertebral fractures is explored and UBP is considered as a possible symptom.

Chapter 11 describes, by way of paper under review, the relationships between breast size, UBP and upper back musculoskeletal tissue sensitivity. The biomechanical rationale for examining these particular tissues in relation to breast size and UBP is explored and using objective methods, this chapter considers skeletal and muscular sources of UBP in women with larger breasts.

The penultimate chapter of this thesis, Chapter 12, presents a time-series examination of the characteristics that change in response to reduction mammoplasty. Upper back pain is examined alongside self-reported health and psychological wellbeing characteristics and objectively-measured physical characteristics before and after surgery to explore the nature and rate of important changes that occur. This chapter considers the relevance of these changes to advancing our understanding of the relationship between breast size and UBP.

Finally, Chapter 13 provides a summary of the thesis and a discussion of its main findings. The significance and clinical implications of the findings are deliberated with due consideration for the strengths and weaknesses of the overall doctoral research project.

Chapter 3   Reliability of posture, upper back mobility, and upper back musculoskeletal tissue sensitivity measurement

3.1   Abstract

Objectives: The reliable assessment of physical characteristics was an important component of this project. The preliminary work of the project presented in this chapter sought to familiarise the thesis candidate with the equipment and procedures proposed for use in the assessment of posture, upper back mobility, and upper back musculoskeletal tissue sensitivity. In order to refine the methods appropriate for use, the aim of this preliminary work was to evaluate the intra-rater reliability of using 1) photographic methods for the measurement of posture and upper back mobility, and 2) digital algometry for the measurement of upper back musculoskeletal tissue sensitivity.

Methods: This was a repeated measures study of 20 mature-aged women (aged $\geq$ 40 years) who had measurements of their posture (photogrammetry), upper back mobility (photogrammetry), and musculoskeletal tissue sensitivity (digital algometry) taken. Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) were calculated.

Results: Intra-rater reliability for posture angles measured digitally from photographs of participants in standing were good (ICC>0.80) and the SEM ranged from 0.9° to 1.6°. Intra-rater reliability for upper back mobility angles measured using photographic methods were also good (ICC: 0.80, 95%CI: 0.66 to 0.91) and SEM was 1.9°. Digital algometry used for the assessment of musculoskeletal tissue sensitivity showed high intra-rater reliability (ICC>0.70) across all measured anatomical sites and SEM ranged from 25.4kPa (sternocleidomastoid) to 92.9kPa (T12).

Conclusion: This preliminary work has established that measuring posture and evaluating upper back mobility using photographic methods, and upper back musculoskeletal sensitivity using digital algometry, are reliable.

3.2   Introduction

This chapter outlines the preliminary work undertaken to test the reliability of measuring posture (refer to section 2.7.10), upper back mobility (refer to section 2.7.7), and musculoskeletal tissue sensitivity (refer to section 2.7.11). The reliability of using the techniques described for measuring these characteristics was considered a potential source of error and was important to examine with the thesis candidate as the assessor. Evaluating reliability of methods was particularly relevant to this project where repeated measures were being employed and changes in characteristics were being assessed (refer to Chapter 12). It was also important to test the practicability of the methods planned for use in a large protocol of measures and to refine aspects of the protocol. One aspect of posture assessment that required refinement for example, was deciding on whether participants sat of stood while photographs of their posture were taken (refer to section 2.7.10). The assessment of posture has previously been shown to vary according to the position of measurement[246].

Previously, for populations not specifically including mature-age women, photographic methods used to assess posture angles of the head, upper back and shoulder have been deemed reliable with ICC values greater than 0.70[242, 244, 257]. The use of photographic methods to accurately assess thoracic extension mobility in young men has also been described as being reliable[100]. For the assessment of musculoskeletal sensitivity, algometry has strong evidence gathered from well-conducted studies, that support its intra-rater reliability (ICC>0.81) and repeatability (ICC>0.86)[250, 251, 258, 259]. These reliability studies have however, often focused on younger and asymptomatic populations.

Procedural steps related to evaluating posture and upper back mobility using photographic methods and that were important to trial included: the accurate placement of photo-reflective markers on anatomical landmarks, the standardised positioning of equipment and participants, and the reliable digitising of images.

Procedural steps related to the measurement of musculoskeletal tissue sensitivity via PPTs using digital algometry that were important to trial included: the ease of identifying and marking specific anatomical sites, the comfortable positioning of the algometer probe at each anatomical site, and the consistency in the application of a standardised rate of pressure at each site.

Based on a review of methods outlined in sections 2.7.7, 2.7.10, and 2.7.11 there were three aims of this part of the preliminary work:

1. To ascertain the reliability of measuring head, upper back, and shoulder posture and upper back mobility angles from photographs using a digitisation process.

2. To compare differences in values and reliability of head, upper back and shoulder posture angles obtained from photographs with a participant in sitting versus standing.

3. To determine the reliability of measuring PPTs in selected tissues of the upper back.

The results of this preliminary work were used to establish whether the measures described were reliable tools for the purpose of measuring posture and evaluating upper back mobility and musculoskeletal tissue sensitivity. In addition, the results were used to inform the methodology of posture measurement where a decision on position of measurement (standing versus sitting) had to be made.

3.3 Design

A repeated measures design was used to establish intra-rater reliability. Guidelines for Reporting Reliability and Agreement Studies (GRRAS) were followed.

3.4 Participants

A convenience sample of 20 mature-aged women (aged ≥40 years) were recruited specifically for this preliminary work (pilot sample). Volunteers responded to posters displayed in a local physiotherapy clinic (Appendix 1a and Appendix 1d). Participants, with and without UBP, were recruited to reflect the characteristics of the samples to be used in the main project. Written informed consent was provided by all participants (Appendix 1b and Appendix 1e) and the study was approved by Curtin University Human Research Ethics Committee (RDHS-34-16 and RDHS-18-16). Participants were excluded if they were unable to read and understand English or if they reported a systemic inflammatory disease, a chronic pain condition, osteoporosis or a neurodegenerative disorder. They were also excluded if they had undergone any surgery involving the upper torso, or had cancer involving the bones in the past five years. Participants who reported the use of medication within the past week that may affect pain perception or sensation were also excluded. All participants completed a screening questionnaire where these criteria were checked (Appendix 1c and Appendix 1f).

3.5 Assessor

All procedures were completed by the thesis candidate, a Musculoskeletal Physiotherapist with postgraduate training and over 10 years of clinical experience. Familiarity with equipment and practice with the measurement techniques was completed in 20+ hours of self-directed study in addition to three 1-hour practice sessions undertaken in correspondence with the doctoral research project supervisors. Eight hours of practice was completed in self-directed mock digitisation and algometry trials.

3.6 Equipment

For the acquisition of all lateral photographs a digital camera (Nikon S3700, Nikon, Japan) was used. The camera was fixed on a tripod and positioned in front of a blank wall 250cm from the participant. A plumb-line was positioned in the field of view to allow referencing of vertical axis. A spirit level positioned on the tripod was used to check horizontal axis. The tripod was adjusted to set the centre of the camera lens level with the mid thoracic spine on each participant when in sitting and when standing. Placement markers on the floor were used to ensure the consistent positioning of participants in front of the camera and a treatment plinth was used for participants to sit on. The analyses of photographic images were performed on a laptop computer using ImageJ software (National Institutes of Health, Bethesda, MD).

In preparation for measuring PPTs, a cloth tape measure and non-permanent make-up pen were used to identify and mark anatomical landmarks of interest. For the measurement of PPTs a digital algometer (Somedic AB, Sweden) was used (

Figure 3.1). A 1cm² circular rubber tip was fitted to the pressure gauge and the device was calibrated using a 100kPa brass calibration weight prior to each use (allowing ± 2kPa). A hand-held button was connected to the device and used by participants to indicate their pain threshold had been reached (refer to section 3.7.2). Upon pushing this button, pressure application automatically stopped and the reading was subsequently displayed in kilopascals (kPa) on the device display screen.

Figure 3.1 Digital algometer ©Somedic, Sweden

3.7 Procedures

All procedures were completed in a treatment room within a physiotherapy clinic.
Assessments were completed in the morning and room conditions (e.g. air temperature,
noise) were consistent for all participants. On the first occasion, participants underwent all
photographic assessments before completing the algometry trials. On the second occasion,
participants completed only the algometry trials.

3.7.1 Photographic procedures:

In preparation for all photographs, participants were asked to remove upper body clothing
sufficient to expose the anatomical landmarks of interest. Participants stood whilst these
were identified.

Posture: preparation and photograph acquisition

For the measurement of posture, photo-reflective markers were fixed with double sided tape
to the spinous processes of C7 and T7, on the tragus of the left ear and lateral mid-point of
the left humerus (refer to Chapter 2, Figure 2.9). The C7 landmark was located as the most
prominent spinous process[114] and the T7 landmark by palpating down 7 spinous processes
from C7 and confirming this in reference to the inferior angle of the scapula[260]. The tragus of
the ear was located as the small pointed eminence of the external ear, situated in front of the
concha[261]. The lateral mid-point of the humerus was the measured centre-point between
fingers that grasped the upper humerus, 1cm below the level of the acromion. Participants
underwent two lateral photographs of their posture, one sitting and one standing. The order
of these was randomised by drawing one of two cards from a cloth bag prior to testing.

For sitting posture, participants sat on a treatment plinth with their feet flat and positioned either side of a placement marker on the floor. The plinth height was adjusted accordingly. Participants were asked to sit comfortably with their eyes looking forward. For standing posture, participants stood with their feet either side of the placement marker on the floor with their arms by their side. Participants were asked to stand comfortably with their eyes looking forward.

Upper back mobility: preparation and photograph acquisition

Prior to capturing the photographs for the assessment of upper back mobility, photo-reflective markers were fixed to the spinous processes of T1, T4, T8 and T12. These were located by counting down from C7[114]. As the most caudal landmark, the location of T12 was confirmed by also locating the twelve rib. Participants then had two photographs taken in sequence (refer to Chapter 2, Figure 2.5). The first photograph was taken with participants at rest. For this, participants stood with their feet either side of the placement marker on the floor with their arms elevated to approximately 70° and hands supported on a 122cm pole. The second photograph was taken with participants in maximal thoracic extension. For this participants stood with their arms fully elevated, reaching up and back as far as possible.

Image analyses

Following acquisition, all images were checked to ensure that all photo-reflective markers were adequately visible and that the image was of good quality. Images were transferred to a laptop for analysis. All images were digitised by the thesis candidate on three separate occasions thereafter, each separated by at least 24 hours.

For the assessment of posture, three angles were measured (refer to Chapter 2, Figure 2.9). Head posture was determined from the angle formed between a line drawn from the tragus of the ear to the seventh cervical vertebrae subtended to the horizontal (craniovertebral angle)[242]. A smaller craniovertebral angle indicated a more forward head posture. Upper back posture was determined from the angle between a horizontal line and a line between the seventh cervical and seventh thoracic vertebrae (cervicothoracic angle)[243]. A larger cervicothoracic angle indicated a more rounded back posture. Shoulder posture was determined from the angle formed between a horizontal line and a line between the mid-point of the shoulder and C7 (shoulder protraction angle)[244]. A smaller shoulder protraction angle indicated a more protracted position of the shoulder.

For the assessment of upper back mobility, images (rest and maximal thoracic extension position) were first prepared by marking lines through the centre of the T1 and T4 markers and through the T8 and T12 markers. The angle was measured in both images where these

two lines intersected (refer to Chapter 2, Figure 2.5). The difference between these angles was calculated to determine thoracic range of movement[100].

3.7.2 Algometry Procedures

In preparation for the algometry trials, 12 anatomical landmark sites were identified and marked on participants with a non-permanent make-up pen. Participants stood whilst six skeletal sites and six muscular sites were located (Figure 3.2).

The spinous processes of selected thoracic vertebrae were used as skeletal sites. These were identified in sequence in a caudal direction by first locating C7 and counting down and marking the spinous processes of T2, T4, T6, T8, T10 and T12. The location of T12 was confirmed by palpating the level of the 12th rib. The spinous processes above T12 were then confirmed by counting up from T12.

All muscular sites were identified on the non-dominant side. The pectoralis major site was located anteriorly on the chest by first palpating the medial and lateral ends of the clavicle and measuring 2cm below the midpoint between these two ends. The levator scapulae site was located as the point 2cm supero-medially from the superior angle of the scapula. The upper trapezius site was located as a point measured 5cm supero-lateral to the superior angle of the scapula. The middle trapezius site was located at a point 2cm lateral and horizontally level with the T3 spinous process which was located by counting down from C7. The lower trapezius site was located as a point 2cm lateral and horizontally level with the spinous process of T8, which had been identified prior. The sternocleidomastoid site was located as a point 3cm below the mastoid process and was marked in the posterior portion of the muscle.

Anatomical sites (position of testing):

1. Pectoralis major (supine)
2. Sternocleidomastoid (supine)
3. Levator scapulae (prone)
4. Upper trapezius (prone)
5. Middle trapezius (prone)
6. Lower trapezius (prone)
7. T2 spinous process (prone)
8. T4 spinous process (prone)
9. T6 spinous process (prone)
10. T8 spinous process (prone)
11. T10 spinous process (prone)
12. T12 spinous process (prone)
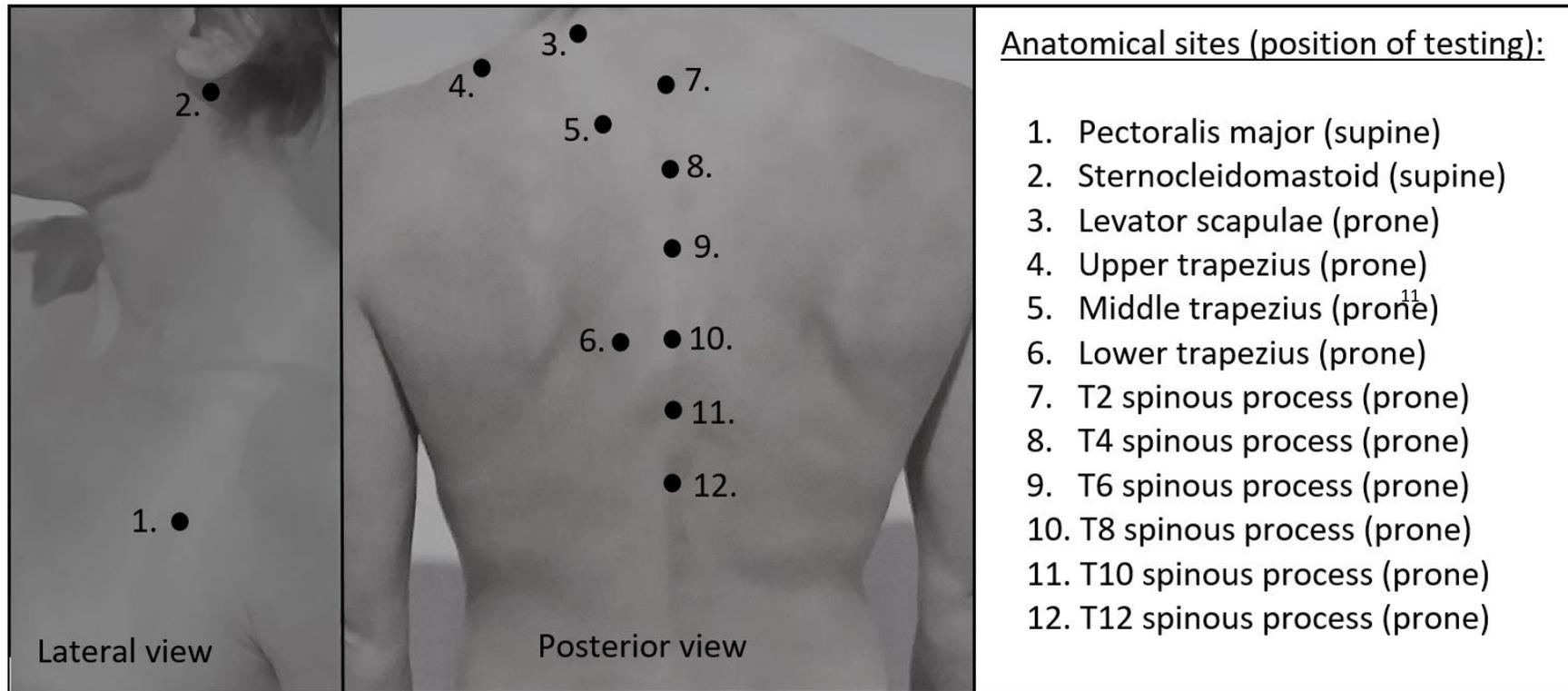
Figure 3.2 Anatomical sites used for assessment of upper back musculoskeletal tissue sensitivity

Prior to testing, participants were familiarised with the procedure and equipment. Each anatomical site was tested three times using a circuit protocol where one measurement of PPT was taken at each of the twelve anatomical sites until the circuit was completed[253]. The order in which the sites were tested was the same for each circuit and this order was randomised using numbered cards selected from a cloth bag prior to testing. Standardised instructions were read to each participant to press the hand-held button as soon as the force of the algometer induced discomfort or pain at the anatomical site (Appendix 5a). Once participants were in position (Figure 3.2), pressure was applied perpendicular to the skin at each site at a steady and consistent rate of 40kPa/s. Pressure readings were recorded for each site and then concealed to avoid bias of subsequent tests on the same site between circuits. An upper limit cut-off of 1000kPa was imposed to avoid injury. Procedures were identical on occasion one and occasion two, 48 hours later.

3.8 Data Analysis

Analyses were completed using SPSS version 24 (IBM; Chicago, IL). Descriptive data of posture angles, upper back mobility and PPTs were analysed for each participant.

To address the first aim, posture angles measured across three digitisation trials in each position (sitting and standing) were assessed using a repeated measures analysis of variance (repeated measures ANOVA). Upper back mobility angles were first calculated for each participant in each digitisation trial by subtracting the angle at rest from the angle at maximal thoracic extension. Upper back mobility angles measured across three digitisation trials were also analysed using repeated measures ANOVA. For posture and upper back mobility measurement, relative estimates of intra-rater reliability were calculated using an ICC (single measures) calculated under a two-way fixed model $(ICC_{3,1})$[262a]. An ICC was defined as poor (<0.75) or good (>0.75)[262b]. An absolute measure of reliability was provided through the calculation of the SEM (square root of the mean square error term of a repeated measures ANOVA). The minimal detectable change (MDC) was determined using the formula $(1.96 \times SEM) \times \sqrt{2}$[262a].

To address the second aim, posture angles captured in sitting were averaged over the three trials and compared to the mean values captured in standing. Mean differences (MD) in angles between positions were assessed using a paired samples t-tests. The criterion for statistical significance was set at $p < 0.05$.

For the third aim, the mean PPTs of three tests taken at each site on occasion one and occasion two were calculated. Correlations were calculated between the mean PPTs of occasion one and occasion two and these were interpreted as weak ($r < 0.3$), moderate ($r = 0.3$-

0.5) or strong (r>0.5)[263]. Mean PPTs of occasion one and two were compared using repeated measures AVOVA. Relative estimates of intra-rater reliability for algometry measurement were calculated using an ICC calculated under a two-way fixed model ($ICC_{3,K}$)[262a]. Standard error of the measurement and MDC were calculated for algometry as described above.

3.9 Results

Twenty women (age range 40 to 77 years) participated in this study. The mean (SD) age, height, and weight respectively were: 59.0 (13.2) years, 72.8 (14.5) kg, and 162.5 (0.7) cm. All participants completed the photographic assessments. Five participants did not attend the second occasion session for repeated algometry trials.

Mean posture angles for each digitisation trial calculated for sitting and standing are shown in Table 3.1. The ICC values that were calculated revealed good values for intra-rater reliability (ICC>0.8) for all posture angles recorded in sitting and standing positions.

Mean (SD) angles for upper back mobility across three digitisation trials were 9.2° (4.3°), 9.4° (4.6°) and 9.7° (4.4°) respectively. Intraclass correlation coefficients revealed good intra-rater reliability (ICC: 0.81, 95%CI: 0.66 to 0.91) in measuring upper back mobility and SEM of 1.9° and MDC of 5.3°. The mean angles across three trials were not statistically different (p>0.05).

Interrater reliability of posture measurements were good regardless of the position of measurement. However, between positions, head and shoulder posture measured in standing attained higher ICC values than the same postures measurement taken in sitting. Conversely, the ICC was higher for measurements of upper back posture taken in sitting compared to standing. The SEM and MDC were smaller for all angles measured in standing compared to sitting. Paired samples t-tests indicated head posture angles were significantly smaller when measured in sitting compared to standing (MD: -4.5°, 95%CI: -2.8 to -6.2°, p<0.001). In contrast, shoulder posture angles were significantly larger when measured in sitting compared to standing (MD: 13.7°, 95%CI: 11.6 to 15.9°, p<0.001). Upper back posture angles were not significantly different between positions (p=0.457).

Table 3.1 Descriptive data summary of posture angles (n=20)

Posture angle		T₁ Mean (SD)(°) n=20	T₂ Mean (SD)(°) n=20	T₃ Mean (SD)(°) n=20	ICC (95%CI)	SEM (°)	MDC (°)
Head	Sit	35.3 (8.5)	35.2 (8.9)	35.2 (8.9)	0.97 (0.94-0.99)	1.4	3.9
	Stand	39.5 (8.5)	40.0 (8.7)	39.7 (8.7)	0.98 (0.96-0.99)	1.2	3.3
Upper back	Sit	110.5 (20.4)	110.8 (20.1)	110.9 (20.2)	0.99 (0.99-0.99)	1.7	4.6
	Stand	107.6 (5.5)	107.5 (5.0)	107.3 (5.5)	0.97 (0.94-0.99)	0.9	2.6
Shoulder	Sit	47.7 (10.2)	47.2 (9.7)	48.1 (8.9)	0.92 (0.85-0.97)	2.7	7.5
	Stand	34.0 (9.9)	34.0 (9.7)	34.0 (9.2)	0.97 (0.95-0.99)	1.6	4.4

Abbreviations: T₁ - Trial 1; T₂ - Trial 2; T₃ - Trial 3; SD - Standard deviation; ICC- Intraclass correlation coefficient; SEM - Standard error of the measurement; MDC - Minimal detectable change; CI - Confidence interval

For algometry trials, the mean (SD) PPT values taken across each site on the two occasions are summarised in Table 3.2. A repeated measures ANOVA revealed no significant differences across the sample for the PPTs measured at each anatomical site between occasion 1 and occasion 2 ($p > 0.05$) and correlations (r) were strong and significant between these mean values (Table 3.2).

Intraclass correlation coefficients that were calculated revealed good values for intra-rater reliability (ICC >0.80) for eight of the 12 anatomical sites and lower values for intra-rater reliability (ICC >0.70) for the remaining four sites (Table 3.2). Calculated SEM values were 93kPa or less across the sites. The MDC values were 257kPa or less for the skeletal sites and 224kPa or less for the muscular sites.

Table 3.2 Descriptive data summary of pressure pain thresholds

Anatomical Site	Occasion 1 Mean (SD) PPT (kPa) (n=20)	Occasion 2 Mean (SD) PPT (kPa) (n=15)	r	ICC (95%CI)	SEM (kPa)	MDC (kPa)
T2	299.6 (139.5)	319.4 (120.2)	0.73	0.84 (0.51-0.95)	69.3	192.2
T4	326.0 (158.5)	336.7 (105.0)	0.80	0.85 (0.54-0.95)	69.3	192.0
T6	312.4 (156.5)	349.3 (123.0)	0.64	0.77(0.30-0.92)	86.7	240.2
T8	332.0 (160.5)	387.0 (111.0)	0.79	0.85 (0.55-0.95)	71.0	196.8
T10	366.6 (164.1)	372.8 (91.6)	0.67	0.73 (0.18-0.91)	87.3	241.8
T12	345.0 (171.1)	377.6 (107.0)	0.64	0.73 (0.20-0.91)	92.9	257.4
Levator scapulae	272.8 (141.1)	304.4 (95.6)	0.80	0.85 (0.56-0.95)	69.3	192.0
Sternocleidomastoid	122.2 (53.3)	114.8 (42.1)	0.74	0.84 (0.52-0.95)	25.4	70.3
Pectoralis major	190.3 (86.6)	170.6 (58.4)	0.86	0.89 (0.66-0.96)	33.3	92.4
Upper trapezius	246.9 (128.4)	277.4 (111.3)	0.55	0.71 (0.13-0.90)	80.7	223.7
Middle trapezius	351.0 (158.6)	353.2 (109.6)	0.77	0.84 (0.52-0.95)	71.8	198.9
Lower trapezius	361.4 (157.7)	392.2 (138.8)	0.84	0.91 (0.74-0.97)	59.9	166.1

Bolded figures - $p<0.05$. **Abbreviations**: PPT - Pressure pain threshold; SD – Standard deviation; *r* - Pearson product-moment correlation coefficient; ICC - Intraclass correlation coefficient; SEM - Standard error of the measurement; MDC - Minimal detectable change; kPa - Kilopascal

3.10 Discussion

With reference to the first aim of this study, the results demonstrated good intra-rater reliability in measuring head, upper back and shoulder posture angles and upper back mobility from lateral photographic images. These findings complement previous evidence showing photographic methods to be reliable for the assessment of posture[242, 244, 245, 257] and upper back mobility[100].

With reference to the second aim of the study, two out of the three posture angles were found to be different between the positions of sitting and standing. Variance in the same posture angle measured in different body positions has been previously reported[246, 264]. Our findings showed that in a sitting position participants trended towards a more forward head and more rounded upper back posture[243, 265]. By contrast, participants' shoulder posture was less protracted in a sitting position but was still within a considerably protracted range[244]. The positional differences that clearly influence posture angles highlights the importance of using standardised procedures for participant positioning when measuring posture from

photographs. The ICC values were consistently good for measures taken in both sitting and standing but those for standing measurements were marginally higher, indicating this to be the more reliable position of measurement. With participants in standing, SEM and MDC values were also consistently smaller across all posture angles, to suggest that angles measured in this position were associated with less measurement error. In summary, posture angles measured with participants in standing were reliably measured with low margins of error and so became the position of choice for the main project.

For the third aim of the study, the results demonstrated generally good intra-rater reliability when measuring PPTs over 12 anatomical sites in the upper back. The results complement previous evidence showing the reliable use of digital algometry by single examiners to assess pressure pain sensitivity[250]. Using female cohorts and similar instrumentation, protocol and pressure application procedures, the mean PPT values calculated in this preliminary work were comparable to previous reports for thoracic spinous processes of T4 and T6[252] and for the soft tissue sites of upper trapezius[259] and levator scapulae[248]. It was reassuring that the PPT values obtained in this preliminary work were consistent with established norms for the anatomical sites where data were available for comparison[248, 252]. The precision of measurements, as indicated through the absolute measure of reliability (SEM), was also comparable to previously published data with values across all anatomical sites under 100kPa[250, 258, 259]. It was important to establish the measurement error for each anatomical site planned for assessment in the main project and the values generated in this preliminary work are a source of reference that allow judgements to be made on whether the differences in PPTs between participants or changes in PPTs within participants, are greater than the imprecision of the measurements themselves.

In conclusion, this preliminary work has established that measuring posture and upper back mobility using photogrammetry, and upper back musculoskeletal tissue sensitivity using digital algometry, are reliable techniques. The study also confirmed that the photographic assessment of head, upper back and shoulder posture angles are more reliably measured with participants in standing rather than sitting. The data produced by this study may be used for the purpose of referencing normal range posture angles in mature-aged women where head (19.1° to 54.2°), upper back (97.8° to 121.6°), and shoulder (17.7° to 50.4°) posture angles have been determined in standing. Finally, the study confirmed that the training undertaken by the thesis candidate, to assess posture, upper back mobility, and upper back musculoskeletal tissue sensitivity, was adequate and that the procedures practiced in this preliminary work were acceptable for use in the main project.

Chapter 4   Measurement of breast size

4.1   Abstract

Objectives: The measurement of breast size was a crucial component of this doctoral research project. A range of methods are available for measuring breast size. These vary in technological sophistication, accuracy and cost. The preliminary work outlined in this chapter aimed to select a suitable self-report and objective method for assessing breast size. This was a reliability and construct validity study of three methods for assessing breast size.

Methods: Using a repeated measures study, the anthropometric method, self-reported bra size and measured bra size for assessing breast size were examined. The breast volume (averaged from left and right breast) of each participant was determined using the anthropometric method where triplicate measures of breast dimensions were obtained. In addition, participants reported their bra size and had their bra size measured using triplicate measures of over and under-bust circumferences. Intraclass correlation coefficient (ICC) and standard error of the measurement (SEM) were calculated for breast volumes calculated using the anthropometric method and for measurements of under-bust and over-bust circumferences. Self-reported bra sizes, converted into ordinal scores (breast size score) were compared to those determined from measured bra size using paired-samples t-tests and correlational analysis.

Results: Nineteen mature-aged women (aged ≥40 years) participated. Breast volumes calculated using the anthropometric method were significantly affected by the position of measurement, had SEM ranging between 212ml to 267ml, and appeared to overestimate true volume when relevant normative data were considered. Intra-rater reliability was excellent for breast volume measurements using the anthropometric method (ICC: 0.99, 95%CI: 0.98 to 0.99), and for under-bust (ICC: 0.99, 95%CI: 0.99 to 0.99) and over-bust (ICC: 0.88, 95%CI: 0.77 to 0.95) circumference measurements. There were no significant differences between breast size scores determined from bra sizes that were self-reported and from those that were measured.

Conclusion: Breast size scores determined from bra sizes provide an ordinal measure of breast size which shows versatility as a self-report and objective method. The process of measuring bra size using under-bust and over-bust circumferences is a reliable technique.

4.2 Introduction

The breast is a complex and morphologically diverse tissue that is not heterogeneous across the female population[266]. The varied geometry and position of the breasts on the chest make their size difficult to quantify[36-39]. The measurement of breast size was an important aspect of this doctoral research project. Before deciding on a measure for breast size (refer to 2.4.3 and 2.7.4), several methods were considered and the suitability of one self-report and two objective methods were examined in the preliminary work outlined in this chapter.

Without removing breast tissue (such as with a mastectomy specimen), breast size can only ever be estimated. Breast size has no universal unit of measurement and has been previously examined as breast volume[22, 23, 39, 45, 267], breast weight[26, 41, 42, 51, 52, 69, 142], bra cup size[40, 53, 65], bra size[47, 55, 160], and as an ordinal breast size score[24, 26, 47]. Breast volume is a unit of breast size measurement that is commonly used in breast-related research (refer to section 2.7.4). The accurate measurement of breast volume is widely-acknowledged to be difficult[36-39, 268] and there are diverse methods, which vary in accuracy, to estimate breast volume[36, 37, 210-215, 269]. The anthropometric method for estimating breast volume requires no specialist equipment and is time-efficient. For these reasons it was the only measure of breast volume suitable for consideration within the large protocol of physical measures planned in the main project.

The anthropometric method uses measured dimensions of the breast to calculate breast volume[210]. The measurements that are obtained in an upright position are used in a geometric formula for calculating the volume of a cone (Figure 4.1)[211].

$$\pi/3 * MP^2 (MR + LR + IR - MP)$$
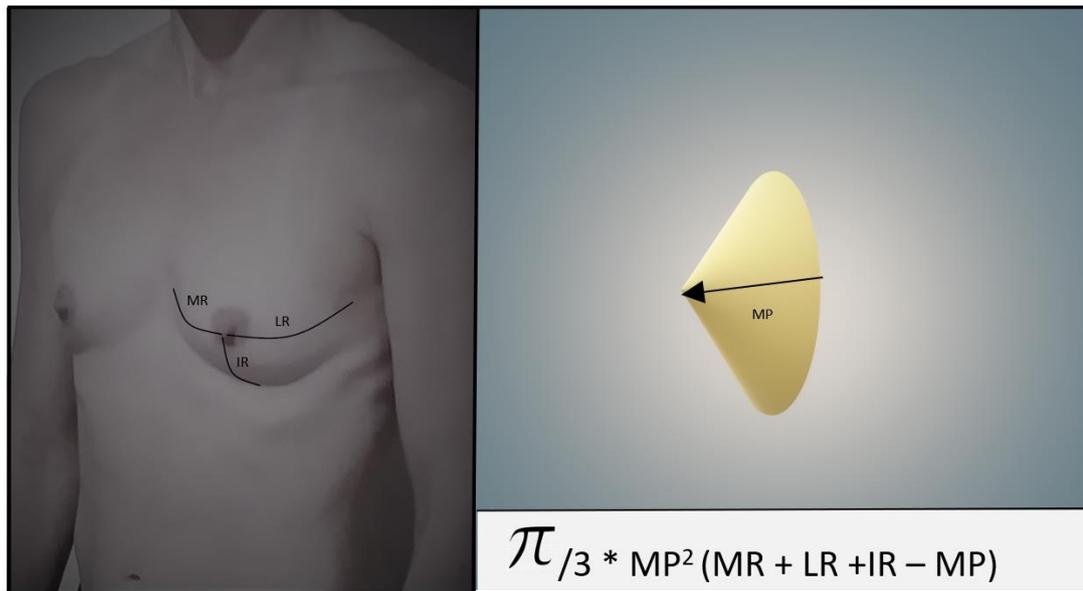
Figure 4.1 Breast dimensions used in anthropometric method to calculate breast volume: LR - lateral breast radius, IR - inferior breast radius, MR - medial breast radius, MP - mammary projection

Acquiring direct measurements of breast dimensions is a reliable technique[270]. Volumes derived using the anthropometric method are reported to correlate strongly with more sophisticated techniques such as 3D scanners (r=0.95) and MRI (r=0.91) where 10 replicate measurements have been previously examined[38]. Similarly high correlations have been noted between the anthropometric method and the gold standard mastectomy specimen technique (r=0.98)[36]. The anthropometric method is well-tolerated by patients and clinicians[37]. It is also a cost effective and time efficient method[36].

Although the strong correlations between the anthropometric method and other breast volume methods suggest an equivalence between them, using the anthropometric method to estimate breast volume in women with large breasts has the potential to be inaccurate[36-38]. Larger breasts and the breasts of older women are commonly more ptotic[271] and, unlike smaller pert breasts in upright positions, larger more ptotic breasts do not conform to the shape of a cone. This has implications when the geometric formula for calculating breast volume is based on the assumption that breasts are cone-shaped. This was anticipated to be problematic for the main project where participants with large and ptotic breasts were likely to be recruited. As a way to overcome this potential problem it was proposed that for the purposes of this project, the anthropometric method could be modified and undertaken with participants in a three-quarter supine rather than in an upright position. Although the construct validity of this adapted technique had yet to be determined, it was anticipated that

this position would allow the breast to conform to a more conical shape irrespective of its size or degree of ptosis.

Bra size is another method for estimating breast size which itself can be self-reported (refer to section 2.4.3) or measured (refer to section 2.7.4). Converting bra size into an ordinal score (BSS) allows breast size to be ranked and provides a numeric breast size variable for use in statistical analysis. A BSS is determined using numerical bra band sizes and alphabetical cup sizes which is similar in concept to the sizing system for unilateral breast prostheses[159]. Breast size scoring methods have been used in prior research[24, 26, 47] and by encompassing both the bra band and cup size these scoring methods overcome the inaccuracies of using bra cup size alone as an indicator of breast size[156, 157]. The BSS method is one way that bra sizes can be used as a surrogate for breast size and this is an alternative method to using volumetric equivalents of bra sizes[39, 157]. The volumetric equivalents of bra sizes have not been employed widely in research and to date, volumes have only been established for a small range of bra sizes using small sample sizes[39, 157]. Because of these limitations, bra sizes converted to equivalent volumes was not a method considered for examination in this preliminary work. Instead, the BSS method (refer to sections 2.4.3 and section 2.7.4) which could be applied as a self-report or objective measure of breast size was considered suitable for examination. The BSS method, however, incorporates a number of assumptions with the potential to affect its accuracy as a breast size measure.

A BSS that is determined from self-reported bra size is subject to reporting accuracy. An important factor determining the accurate reporting of bra size is whether the reporter wears a well-fitted bra that is the correct size for her. Since women commonly wear an incorrectly fitted and sized bra[24, 47, 140, 141, 143, 144, 156], it is possible that reporting accuracy could be problematic where self-report measures of bra size are being used to determine a BSS.

Where self-report and measured bra sizes have been previously compared, the greatest discrepancies have been found in women with large breasts[144, 156]. These women typically overestimate their cup size and underestimate their band size[156]. In a prior study that applied a ordinal scoring system, similar to the BSS method, it was reported that 93% of participants were wearing an incorrectly-sized bra, based on the comparison of self-reported and measured bra size[24]. It was not reported in this study, however, whether this was determined from raw bra sizes or after bra sizes had been converted into an ordinal BSS. Increments in BSS follow a numeric pattern that increases sequentially relative to bra size which allows some accommodation of over or under-estimates of bra band or cup size. For someone who reports her bra size as a 12D but who is measured as a 14C (under-estimates her bra band size by one size and overestimates her cup size by one size) there would be no discrepancy in

BSS because these represent the same BSS. So although the incorrect bra was worn and reported, the BSS still provides a reasonable representation of breast size. It would be informative to know however, if BSS values determined from self-report and measured bra sizes are comparable. This would provide confidence that there are not large margins of error between self-reported and measured bra sizes.

Another factor that could affect reporting accuracy of bra size is the variability in sizes between different styles and brands of bra[156]. In the absence of a universal system of bra sizing, someone who reports wearing a Berlei bra in size 12C may not have the same breast size as someone else who reports wearing a Triumph bra in a 12C. Although the variations in sizing between bra brands are likely to be small, there is potential for the same bra size across different bra brands to produce a different BSS. This is an important consideration when BSS values are derived from self-reported bra size.

Measuring bra size[206] is also subject to a number of influences and these largely relate to the assessment of under and over-bust circumferences (refer to section 2.7.4). Two factors that are known to affect circumferential measurements are respiratory state[156] and breast position[140]. Measurements that are taken at the end of expiration[156] and with the breasts supported within a bra[140] can reduce possible errors in determining bra sizes from under and over-bust circumferences.

Despite under and over-bust circumferences being used frequently in bra-related research[47, 55, 140, 156], the reliability of taking these measurements has not been previously documented. Duplicate under-bust or over-bust circumferential measurements that differ by greater than 2cm will result in a difference in bra size[218]. This could affect the BSS determined in duplicate measures if, for example, both under and over-bust measurements were discrepant. The reliable measurement of under and over-bust circumferences is therefore imperative to determining an accurate BSS from measured bra size.

This chapter presents the preliminary work that examined three methods of breast size measurement. The anthropometric method for estimating breast volume was chosen for trial as an objective measure of breast size. In addition, measured bra sizes converted into ordinal BSS values using the BSS method were an alternative objective measure of breast size that was examined. In the absence of more precise self-report measures, bra size was chosen for trial as a self-report measure of breast size. The conversion of self-reported bra sizes into ordinal BSS values was an aspect of the BSS method that required some refinement. Related to the chosen methods, this preliminary work had the following aims:

1. To ascertain the construct validity and intra-rater reliability of obtaining volumetric measurements of breasts using the anthropometric method in gravity dependent (upright) and non-gravity dependent (three-quarter supine) positions.

2. To compare BSS values determined from measured bra sizes using the bra sizing charts of three different bra manufacturers.

3. To determine the intra-rater reliability of measuring under and over-bust circumferences.

4. To ascertain whether BSS values determined from self-reported bra size differ significantly from those determined from measured bra size.

4.3 Design

This was a repeated measures study of breast size using three methods. Using triplicate measurements on one occasion, breast volume was determined using the anthropometric method (method 1). On one occasion, bra size was self-reported and converted into a BSS (method 2). Using triplicate measurements on one occasion, under and over-bust circumferences were converted into BSS values (method 3). Results were reported in accordance with GRRAS[272].

4.4 Participants

A sample of convenience (pilot sample, n=20) was recruited specifically for the preliminary work of this doctoral research project (refer to section 3.4). A poster displayed in a local physiotherapy clinic attracted volunteers to participate in this branch of the preliminary work (Appendix 1g). In addition to the exclusion criteria outlined in section 3.4, this branch of the preliminary work also excluded volunteers if they had undergone any form of breast surgery or had an objection to disrobing sufficiently for the purposes of the study. All participants provided written informed consent and the study (Appendix 1h) was approved by Curtin University Human Research Ethics Committee (RDHS-35-16).

4.5 Assessor

The thesis candidate completed all measures. Practice of the measurement techniques was completed in self-directed study and practice sessions prior to the study.

4.6 Equipment

A cloth tape measure was used to complete all anthropometric measurements and also to measure under-bust and over-bust circumferences. The bra sizing charts of three bra

manufacturers (Berlei: https://www.berlei.com.au/size-charts; Playtex: https://www.playtex.com.au/fit-guide; Triumph: https://au.triumph.com/pages/size-charts) were used for determining bra sizes. Breast size scores were determined using a BSS conversion chart (version 1, V_1) (Figure 4.2). This was specifically developed using a scoring system originally developed for sizing unilateral breast prostheses[159].

Breast Size Score (BSS) Conversion Chart V¹		Band size									
		8	10	12	14	16	18	20	22	24	26
Cup size	AA	0	1	2	3	4	5	6	7	8	9
	A	1	2	3	4	5	6	7	8	9	10
	B	2	3	4	5	6	7	8	9	10	11
	C	3	4	5	6	7	8	9	10	11	12
	D	4	5	6	7	8	9	10	11	12	13
	DD	5	6	7	8	9	10	11	12	13	14
	E	6	7	8	9	10	11	12	13	14	15
	F	7	8	9	10	11	12	13	14	15	16
	G	8	9	10	11	12	13	14	15	16	17
	H	9	10	11	12	13	14	15	16	17	18
		Breast size score									

Figure 4.2 Breast size score conversion chart V¹

4.7 Procedures

All procedures were completed in a secure treatment room within a physiotherapy clinic described in Chapter 3. This branch of the preliminary work was completed at the same time as the reliability study described in Chapter 3. Breast size measures were completed following all other procedures.

4.7.1 Anthropometric method

The validated anthropometric method procedure outlined by Qiao et al[211] was used. With participants in sitting without a top or bra, anatomical landmarks were located and marked using a non-permanent make-up pen. The medial border of the breast was marked as the most medial boundary of the breast, level with the nipple. The lateral border was marked as the most lateral boundary of the breast, level with the nipple. The inframammary fold was marked as the most inferior boundary of the breast directly under the nipple, where the breast and chest joined. The mid sternal line was marked as the centre point on the sternum. This was located using the sternal notch for vertical reference and medial boundary of the breast for horizontal reference. Four breast dimensions relative to the anatomical landmarks for the right and then the left breast were obtained using a tape measure with participants in sitting and then laying three-quarter supine. All measurements were recorded in centimetres rounded to the nearest millimeter. For sitting measures, participants sat on a treatment plinth

with their feet flat on the floor and their hands on their hips. For three-quarter supine measures, participants were first asked to lay on their side and then rotate their thorax backwards until the nipple of the uppermost breast was vertical and a more conic shape of the breast was attained. The medial breast radius (MR) was the measured distance (cm) from the nipple to the medial border of the breast (Figure 4.1). The lateral breast radius (LR) was the measured distance from the nipple to the lateral border of the breast (Figure 4.1). The inferior breast radius (IR) was the measured distance between the nipple and the inframammary fold (Figure 4.1). The mammary projection (MP) was the measured distance between the nipple and the mid sternal line in the lateral plane (Figure 4.1). Breast dimensions were measured three times on each breast, separated by a 10-minute interval. The order in which the breast dimensions were measured was randomly decided using cards selected from a cloth bag prior to testing. The breast dimensions for the right and left breast were entered into the geometric formula $\Pi/3*MP^2$ (MR+LR+IR-MP) to calculate the breast volume (to the nearest whole milliliter) of each breast respectively[211].

4.7.2 Self-reported bra size converted into a breast size score

Determining self-reported breast size was a two-step process (Figure 4.3). Participants first indicated their current bra size (band and cup size) in Australian units in the screening questionnaire completed at recruitment (Appendix 1i). Bra sizes were then converted to an ordinal BSS between 0-18 (Figure 4.2).

4.7.3 Measured bra size converted into a breast size score

Determining measured breast size was a three-step process (Figure 4.3). First, bra size was measured using under and over-bust circumferences measured in centimetres to the nearest millimetre[206]. Participants stood, wearing their bra with their arms elevated to allow circumferential measures of the chest to be taken. For under-bust measures the tape measure was positioned firm around the chest, horizontally level and under the breasts. For over-bust measures the tape measure was positioned firm around the chest, horizontally level with both nipples. Participants were asked to exhale and hold this breathe whilst measurements were taken. Under-bust and over-bust measures were taken three times (separated by 5-minute intervals) for each participant. Second, these measures were averaged and the mean used to determine a bra size by referring to the bra sizing charts of three different manufacturers[218-220]. Third, bra sizes, determined according to each manufacturer, were converted to ordinal BSS values (Figure 4.2).

Self-reported breast size

Participants reported their bra size (cup and band size)

Bra size was converted into an ordinal score using Breast size score conversion chart V_1

Self-reported breast size score
(single BSS score)
BSS (self-reported)

Step 1 → Step 2 → Step 3

Measured breast size

Participants had under and over-bust circumferences measured three times

Average of under and over-bust circumferences were converted into a bra size using bra manufacturers bra sizing charts

Bra size was converted into an ordinal score using Breast size score conversion chart V_1

Measured breast size score
(three BSS scores)
BSS (Burlei)
BSS (Playtex)
BSS (Triumph)

Figure 4.3 Determining breast size scores during preliminary work

79

4.8 Data Analysis

Analyses were completed using SPSS version 24 (IBM; Chicago, IL). To address the first aim, descriptive data of breast volumes determined for the left and right breasts were summarised over three trials. The breast volume for each participant in each position per trial was calculated using the mean volume of left and right breasts. Calculated volumes were compared with relevant normative reference data[210] to judge construct validity. Differences in breast volumes between trials in each position (sitting and three-quarter supine) were assessed using a repeated measures ANOVA with the criterion for statistical significance set at $p<0.05$. Relative estimates of intra-rater reliability (ICC) were calculated using an ICC (average measures) calculated under a two-way fixed model ($ICC_{3,k}$) for each position (sitting versus three-quarter supine). Standard error of the measurement (square root of the mean square error term of a repeated measures ANOVA) provided an absolute measure of reliability. The MDC was determined using the formula $(1.96 \times SEM) \times \sqrt{2}$[262a].

To address the second aim, Pearson product-moment correlation coefficients (*r*) between BSS values according to three bra manufacturers (BSS (Berlei); BSS (Playtex); BSS (Triumph)) were examined. The strength of correlation was interpreted as low ($r<0.3$), moderate ($r=0.3-0.5$) and strong ($r>0.5$)[263]. Paired samples t-tests were used to identify significant ($p<0.05$) differences between the BSS values.

For the third aim, under and over-bust measurements taken over three trials were assessed for differences using a repeated measures ANOVA and an ICC (single measures) calculated under a two-way fixed model ($ICC_{3,1}$) was used to estimate intra-rater reliability.

Correlation analysis and paired comparisons were used to address the fourth aim. Measured BSS values were correlated with self-reported BSS values. Paired samples t-tests identified significant differences between these BSS values.

4.9 Results

Nineteen women participated in this study. Their mean age, height, weight, and BMI respectively were: 59.6 (12.1) years, 162.3 (6.7) cm, 73 (14.6) kg, and 27.7 (5.4) kg/m². Of the 20 participants recruited, one participant was excluded from the pilot sample for reporting prior breast surgery at the time of measurement.

Using the anthropometric method, mean breast volumes calculated with participants in sitting ranged from 958ml to 11892ml (median: 4981ml IQR: 3164ml) whilst those calculated with participants in three-quarter supine ranged from 1046ml to 10541ml

(median: 4497ml IQR: 1694ml) (Table 4.1). Breast volumes calculated in sitting were significantly larger than breast volumes calculated in three-quarter supine (MD: 633ml, 95%CI: 275 to 991.ml, p=0.002). Reliability estimates (ICC) for volumes calculated in sitting and three-quarter supine were identical at 0.99 (95%CI: 0.98 to 0.99). The SEM and MDC were lower for measures calculated in three-quarter supine compared to those in sitting (Table 4.1).

Table 4.1 Descriptive data summary of breast volumes (anthropometric method)

Position	Mean Volume[a] (SD)(ml) T_1	Mean Volume[a] (SD)(ml) T_2	Mean Volume[a] (SD)(ml) T_3	ICC (95%CI)	SEM (ml)	MDC (ml)
Sitting	5456 (2771)	5396 (2570)	5518 (2700)	0.99 (0.98-0.99)	267	741
Three-quarter supine	4818 (2148)	4863 (2173)	4791 (2038)	0.99 (0.98-0.99)	212	585

[a] Mean values calculated from the left and right breast per trial. **Abbreviations**: T_1 - Trial 1; T_2 - Trial 2; T_3 - Trial 3; ICC - Intraclass correlation coefficient; CI – Confidence interval; SEM - Standard error of the measurement; MDC - Minimal detectable change; ml - Millilitres.

Mean (SD) BSS values determined from measured bra sizes were 7.2 (2.5), 7.3 (2.6) and 7.0 (2.5) using the Berlei, Playtex and Triumph bra sizing charts respectively. Breast size score values using the Berlei sizing chart were strongly correlated to those determined using the Playtex and Triumph conversion charts (Table 4.2). The BSS values determined using the Triumph bra sizing chart were significantly smaller than BSS values determined using the Playtex (MD: -0.3 sizes, 95%CI: -0.5 to -0.8 sizes, p=0.021) and Berlei (MD: -0.2, 95%CI: -0.4 to 0.0, p=0.010) bra sizing charts. Rounded to the nearest whole score however, the mean BSS values were the same (size 7) across all bra manufacturer brands.

Table 4.2 Correlation matrix of breast size scores

	BSS (Berlei)[a]	BSS (Playtex)[a]	BSS (Triumph)[a]
BSS (self-reported)	**0.78**	**0.76**	**0.78**
BSS (Berlei)[a]		**0.99**	**0.99**
BSS (Playtex)[a]			**0.98**

[a] BSS determined from measured bra size (under and over-bust circumferences); Bolded figures - p<0.05. **Abbreviations:** BSS - Breast size score

Mean under-bust circumferential measures of 84.7cm, 84.8cm and 84.9cm over three respective trials were not significantly different (p=0.148) and recorded a test-retest reliability ICC of 0.99 (95%CI: 0.99 to 0.99). Mean over-bust circumferential measures of

100.6cm, 100.7cm and 99.3cm over three trials were also not significantly different (p=0.441) and recorded an ICC of 0.88 (95%CI: 0.77 to 0.95).

The mean (SD) BSS of 7.2 (1.9) determined from self-reported bra sizes showed a strong correlation (r>0.7) with BSS values determined from measured bra sizes irrespective of which bra manufacturers sizing chart was used to determine bra size and BSS (Table 4.2). There were no significant differences between BSS values determined from self-reported and measured bra sizes (p>0.05).

4.10 Discussion

The purpose of this study was to determine a suitable self-report and objective measure of breast size for use in the main project.

The anthropometric method is documented as a valid and reliable measure of breast volume[37, 38]. The basis of the geometric formula used to calculate volume in this method is that the breast is a cone-shaped structure. This is arguably inaccurate if used with women with large ptotic breasts in upright positions where breasts do not conform to a cone-shape. The results of this study demonstrate this potential flaw by showing that the volume estimation is significantly influenced by the position in which the dimensions (used for volume calculation) of the breast are measured. Although measures taken in these two positions were highly reliable, the potential for inaccuracy is clear and important. The range of breast volumes calculated for participants in this study, regardless of the position of measurement, far exceeded those reported in previous studies whose samples include women with comparable bra sizes[156, 208, 210]. The volumes that were recorded also exceeded those that have been recorded in women with macromastia undergoing reduction mammoplasty[40, 51, 66] and those in the latter stages of pregnancy[207]. On this basis the data collected for this sample using the anthropometric method the volumes calculated were deemed erroneous and indicated that this method has the potential to significantly overestimate breast volume in women with ptotic breasts.

The anthropometric method relies heavily on the consistent and accurate location of the breast boundaries for the correct calculation of volume. In participants with large ptotic breasts this was found to be difficult in this preliminary work. The over-estimation of volume measurement was speculated to be the result of difficulties in locating the breast boundaries and the inflated mammary projection (MP) values in ptotic breasts. Similar difficulties have been recognised in prior research using other breast volume measures such as 3D scanners[39, 54, 216].

Breast size scores that are determined from bra sizes provide a simple indicator of breast size which have been used in previous research[24, 26, 47]. The results of this preliminary work have demonstrated the versatility of the BSS method by using it with self-reported and measured bra sizes. The assessment of under and over-bust circumferences to measure bra size were found to be reliable processes in the hands of the thesis candidate. This adds confidence in using the BSS method to objectively assess breast size in the main project.

In agreement with prior research there was some variation in the bra sizes determined when referring to the bra sizing charts of different bra manufacturers[141, 156]. The small differences in under and over-bust lengths ascribed to each bra size in the sizing charts of different bra manufacturers also meant the BSS values that were determined were different. Although some of these differences were statistically significant, rounded to the nearest whole score, BSS values were in fact identical. A noted problem with the Playtex and Berlei bra sizing charts was the overlapping ranges of over-bust values for each bra size which meant that one of two cup sizes could be determined from the same circumferential over-bust measure. A difference in 1-cup size on the same band was sufficient to create a 1-point difference in BSS and this may explain why the BSS values determined using the Triumph sizing chart differed from both the Berlei and Playtex charts but between the latter two manufacturers there were no significant differences. Whilst the overlapping ranges might be considered a limitation of the Berlei and Playtex conversion charts, the Berlei chart provides the widest range of under-bust and over-bust measures and has been used extensively in prior research[39, 54, 141, 157]. For these reasons, the Berlei bra sizing chart was chosen for use with the BSS method in the main project. To refine the breast sizing protocol in the main project, a single BSS conversion chart was developed by the thesis candidate (version 2, V_2) (Appendix 4b). This incorporated the under and over-bust circumferential reference data from the Berlei bra sizing chart and allowed self-reported and measured bra sizes to be converted into a BSS using a single chart for reference in the main project.

The final aspect of this preliminary work investigated the strength of the relationship between BSS values determined from self-reported and measured bra sizes. A common finding in prior research is that women often wear and therefore report, an incorrectly fitted and sized bra[47, 141, 143]. This raises the possibility that self-reported bra sizes may be an inaccurate representation of actual bra size and subsequently, breast size. The findings of this preliminary work does not support this. The BSS values determined from self-reported and measured bra size were not significantly different and shared a strong correlation. This provides some confidence that self-reported bra sizes are comparable to measured bra sizes and therefore are a reasonable representation of breast size.

In conclusion this study has demonstrated the challenges involved with breast volume measurement using the anthropometric method. The potential for inaccuracies when used with women with large ptotic breasts, which is not overcome by altering measurement position, makes the anthropometric method unsuitable for use in the main project. Breast size scores determined from bra sizes (BSS method) provide an ordinal measure of breast size which shows good versatility as a self-report method and reliability as an objective method. The BSS method allows the breast sizes of participants to be ranked and is appropriate to use where an ordinal unit of breast size is required for assessing the strength and direction of association between breast size and other variables. Thus, the BSS method was deemed suitable for the main project.

Chapter 5   Measurement of thoracic kyphosis

ORIGINAL ARTICLE

Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods

L. Spencer[1] · R. Fary[1] · L. McKenna[1] · R. Ho[2] · K. Briffa[1]

Abstract

Summary The Flexicurve ruler is an alternative method to radiographs for measuring thoracic kyphosis (curvature), but it is not certain that it is comparable. This study shows that Flexicurve can estimate radiographic vertebral centroid angles with less error than Cobb angles but that its accuracy would be inadequate for most clinical purposes.

Introduction The Flexicurve ruler provides a non-radiological method of measuring thoracic kyphosis (TK) that has moderately strong correlations with the gold-standard radiographic Cobb angle method, while consistently underestimating the TK angle. Cobb angles can include measurement errors that may contribute to poor agreement, particularly in older populations. The vertebral centroid angle could be a better radiographic reference method for the validation of Flexicurve. Using two separate radiographic measurements of TK, we examined the validity of Flexicurve. We aimed to ascertain the level of agreement between measures and to empirically explore reasons for between-method differences.

Methods TK angles determined using Flexicurve and radiographic Cobb and vertebral centroid methods were compared using data from 117 healthy postmenopausal women (mean (SD) age 61.4 (7.0) years). Bland and Altman plots were used to assess differences between methods. Age, bone mineral density and body mass index were examined as characteristics that might explain any differences.

Results Flexicurve angles were scaled prior to analysis. There was no statistically significant difference between angles produced by Flexicurve and vertebral centroid methods (MD − 2.16°, 95%CI − 4.35° to 0.03°) although differences increased proportionally with TK angles. Flexicurve angles were significantly smaller than radiographic Cobb angles and depending on the scaling method used, systematic error ranged between − 2.48° and − 5.19°. Age accounts for some of the differences observed ($R^2 < 0.08$, $p < 0.005$).

Conclusions TK measured using the Flexicurve shows better agreement with the radiographic vertebral centroid method, but inaccuracy of the Flexicurve increases with increasing angle of kyphosis.

Keywords Flexicurve method · Postmenopausal women · Thoracic kyphosis

Introduction

Thoracic kyphosis (TK) describes the curvature of the spine in the sagittal plane between T1 and T12. Normal TK angles are considered to be between 20 and 40° [1], but with advancing age, these angles increase, particularly in women after menopause [2, 3]. The accurate measurement of TK has clinical importance for assessing the physical and functional consequences of TK and risk factors related to its progression. There are a range of options available for the measurement of TK. These can be categorised into radiological and non-radiological methods.

The Flexicurve ruler (Flexicurve) is a simple non-radiological method of measuring TK in the clinic. This flexible length of plastic-coated lead is shaped to the contour of the spine. An outline of this shape is traced onto paper, and measured dimensions are used to calculate either a kyphosis index (KI) or kyphosis angle. It allows clinicians to measure

✉ L. Spencer
   Linda.spencer@curtin.edu.au

[1] School of Physiotherapy and Exercise Sciences, Curtin University, GPO Box U1987, Perth, WA 6845, Australia

[2] Perth Radiological Clinic, Perth, WA, Australia

 Springer

TK at low cost and without exposing patients to radiation, making it suitable for repeated regular clinical use. High levels of inter- and intra-rater reliability have been consistently reported for Flexicurve [4–9]. For the purposes of this study, the Flexicurve kyphosis angle was of interest because, and unlike the KI, it provides an angular measure of TK which allows comparison to radiographic measures.

A number of mathematical formulae have been proposed for the calculation of the Flexicurve angle [4, 6, 10–12]. Greendale et al. [4] used geometric formulae to calculate an inscribed angle of kyphosis. By definition, the inscribed Flexicurve kyphosis angle is expected to be smaller than radiographic angles and for this reason requires additional scaling [4] to result in values equivalent to radiographic angles [4]. The scaling metrics suggested by Greendale et al. [4] have, however, yet to be validated in non-hyperkyphotic populations. In addition, these scaling metrics were developed to predict a *constrained* Cobb angle, measured from T4 to T12 and may differ from those required to predict a global Cobb or vertebral centroid angle measured from T1 to T12.

Flexicurve kyphosis angles have been reported to correlate strongly with radiographic Cobb angles, across populations of diverse age ranges (10–96 years old) [4, 6, 8, 9, 12]. Despite a strong correlation, a lack of agreement between Flexicurve and Cobb angles casts doubt over the validity of the Flexicurve as a TK measurement tool [4, 6, 8, 12]. Across populations of varied age and sex, and in those with and without pathology and pain, discrepancies of around 20° are commonly described between Flexicurve and Cobb angles. Reasons for the discrepancies have not been fully explored but could be explained by methodological differences in addition to physical characteristics that may vary between individuals being measured. Body mass index (BMI), for example, can affect the accurate use of Flexicurve in the thoracic [8] and cervical spine [13].

The Cobb angle, taken from a standing lateral radiograph, has a measurement error of less than 5° [14]. However, in some cases, errors associated with duplicate measurements taken by a single rater have been recorded as high as 30° [15]. The Cobb angle is formed by the intersection of lines perpendicular to the superior end plate of T1 and inferior end plate of T12 [16]. In cases where the endplates of these vertebrae (T1 and T12) are affected by degenerative pathologies such as osteoarthrosis or osteoporosis with vertebral fractures, there can be a direct effect on the inclination of the lines used to determine the angle, and therefore the angle itself [14, 17]. A Cobb angle that is influenced by regional deformities at T1 or T12 could overestimate the true TK and this is more likely in older populations [14]. Therefore, Cobb angles may differ from other measures of TK, such as Flexicurve, particularly if these comparisons are made using populations who are older or who have significant pathology affecting the spine.

The vertebral centroid angle is an alternative radiographic assessment of TK advocated for older populations [14]. This angle, also obtainable from a standing lateral radiograph, uses the midpoints of selected vertebral bodies (T1, T2, T11, T12) to measure TK [18]. It is less affected by endplate tilt which potentially makes it a more representative measure of the full contour of the thoracic spine and more appropriate for use over the Cobb angle where pathology or age-related vertebral changes may be a problem. The vertebral centroid angle method has less measurement error and better reliability than the Cobb angle method in measuring the sagittal curvature of the lumbar spine [19, 20]. The vertebral centroid angle method has not previously been compared to the Flexicurve for the assessment of TK in older females where age-related and pathological vertebral changes may be prevalent. Since both the centroid and Flexicurve angles capture the full thoracic curvature and are unaffected by vertebral body abnormalities, the angles they produce could be similar. An improved agreement between Flexicurve and radiographic vertebral centroid angles could help confirm the validity of Flexicurve and may illustrate the limitations of using Cobb angles as the radiographic reference for TK in older female populations.

In this study, we examined the validity of the Flexicurve method using two separate radiographic measurements of TK. The aim was to ascertain the level of agreement between these measures and to empirically explore the reasons for between-method differences using a novel approach. Differences in the physical characteristics of people being measured were reasons of particular interest, but with the potential to influence Flexicurve kyphosis angles, different scaling approaches to calculating this angle were also examined. We hypothesised that Flexicurve angles would show better agreement with vertebral centroid angles than with Cobb angles and that age, bone mineral density (BMD) and BMI may account for some of the between-method discrepancies.

Methods

This was a cross-sectional study with data collected as part of another study examining relationships between physical characteristics and upper back pain in postmenopausal women. Participants volunteered for the study in response to radio and newspaper advertisements as well as social and word of mouth communication. All participants provided written informed consent. The study was approved by the Human Research Ethics Committee at Curtin University (RDHS-267-15). The exclusion criteria for the study were (1) menstruated within the last 12 months, (2) previous thoracic spine surgery, (3) reported systemic inflammatory conditions or neurodegenerative disorders, (4) known pathology of the thoracic spine and (5) previous cancer involving bone.

Participants attended a university-based health clinic on one occasion for measurement of height (cm), weight (kg), BMI (kg/m^2), BMD (averaged bilateral neck of femur (g/cm^2) (dual energy X-ray absorptiometry) and TK using Flexicurve. On a separate occasion, within an average of 7 days, participants attended a local radiological clinic to complete the radiological assessment of TK.

Non-radiological measures of thoracic kyphosis: Flexicurve

A musculoskeletal physiotherapist with over 10 years clinical experience, who had completed over 50 h of practice in using Flexicurve [21], completed the Flexicurve measures of TK. Participants removed all their upper body clothing to expose the spine, and the spinous processes of C7 and S2 were located and marked with a non-permanent pen. The spinous process of C7 was palpated as the most prominent spinous process [22] and S2, by counting downwards from C7. The level of S2 was confirmed as the central point between the left and right PSIS, visually located as skin dimples [23]. Participants stood comfortably upright, while the Flexicurve ruler was placed against the spine from C7 to S2 [24, 25]. The shape of the Flexicurve was traced onto graph paper and the points representing C7 and S2 were joined using a ruled line. The inflexion point where this ruled line crossed the tracing was identified and marked to represent the end of the thoracic length, assumed to be T12 [24]. The widest point between the tracing and the ruled line perpendicular to the thoracic length was identified as the thoracic width. An *inscribed Flexicurve kyphosis angle* (°) was calculated for each participant using the thoracic length (TL) and thoracic width (TW) dimensions and the mathematical formula (TK = arctan (TW/TL1) + arctan (TW/TL2) as previously described [4] and illustrated in Fig. 1. The inscribed Flexicurve values were subsequently scaled to convert non-radiological angles to equivalent radiographic angles [4]. Using a previously developed method, inscribed Flexicurve kyphosis angles were scaled by 1.53 for comparison with Cobb angles (Fig. 1). It should be noted, however, that this method of scaling was developed to produce values equivalent to *constrained* Cobb angles (T4–T12) [4]. The angles calculated using these scaling metrics were therefore referred to in this study as *Flexicurve kyphosis angle (scaled constrained Cobb)*. Additionally, using an equation developed from our own data, inscribed Flexicurve kyphosis angles were scaled to produce an equivalent *global* Cobb angle (T1–T12) and these are referred to as *Flexicurve kyphosis angle (scaled global Cobb)*. Also, using our own scaling metrics, Flexicurve kyphosis angles were scaled to produce an equivalent vertebral centroid angle (*Flexicurve kyphosis angle (scaled global centroid)*).
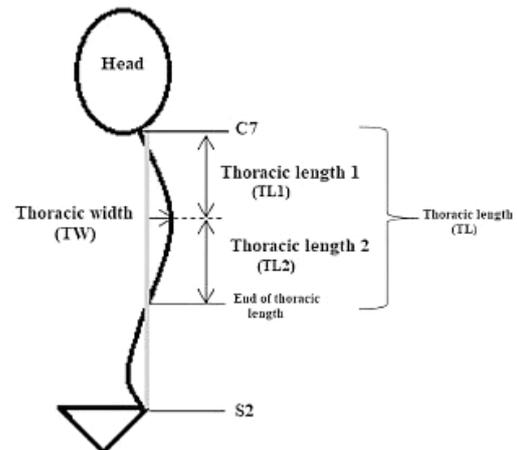
Fig. 1 Flexicurve kyphosis angle. Dimensions used in *inscribed Flexicurve kyphosis angle* calculation (Thoracic kyphosis = arctan (thoracic width (TW)/thoracic length 1 (TL1) + arctan (thoracic width (TW) /thoracic length 2 (TL2) [4]; and *Flexicurve kyphosis angle (scaled constrained Cobb)* calculation (= arctan (TW/TL1) + arctan (TW/TL2) × 1.53

Radiological measures of thoracic kyphosis: Cobb and vertebral centroid methods

Radiographic assessments were completed at community-based radiological clinics of one organisation. Standardised instructions for radiographers were to take a single right-sided lateral thoracic X-ray with the participant's arms flexed to 90°. The X-ray device was positioned at a film focus distance of 120 cm with the beam centred on the mid thoracic vertebrae. The Cobb angle and vertebral centroid angle were determined digitally (InteleViewer, Inteleard, Montreal, Canada) using the same X-ray on separate occasions by a single radiologist (RH) blinded to the aims of the study. Thoracic intervertebral osteoarthritis was judged radiologically as 'nil-mild' or 'moderate-severe'. Thoracic vertebral bodies with a loss in height of ≥20% in comparison to normal adjacent vertebrae were recorded as vertebral fractures [26].

1. Cobb method

Cobb angles (°) were measured digitally using the superior end plate of T1 and inferior end plate of T12 as previously described [16]. Images were optimised by adjusting digital window level and by using imaging software filter tools. Where there was obstruction of the T1 due to overlapping soft tissue, the next most superior vertebra visible was used. Where the viewing of T12 was obstructed, the next most inferior visible vertebra was used.

88

2. Vertebral centroid method

Vertebral centroid angles (°) were measured digitally using a four-segment method (global angle) previously described [18]. Using the two uppermost visible vertebrae (T1, T2) and the two lowest most visible vertebrae (T11 and T12), the corners of each vertebrae (segment) were first digitised and diagonally connected to locate the vertebral body midpoints. The vertebral centroid angle was determined where a line, connecting the midpoints of the upper two segments and a line connecting the midpoint of the lower two segments, intersected (Fig. 2).

Data analysis

Data were analysed using SPSS version 24 (IBM; Chicago, IL).

Flexicurve kyphosis angles were examined according to the method used to calculate the angle. The following Flexicurve angles were reported:

*   Flexicurve kyphosis angle (inscribed)—calculated as previously described and not scaled [4]
*   Flexicurve kyphosis angle (scaled constrained Cobb)—calculated as previously described and scaled to 1.53 [4]
*   Flexicurve kyphosis angle (scaled global Cobb)—calculated using our own scaling metrics (see below).
*   Flexicurve kyphosis angle (scaled global centroid)—calculated using our own scaling metrics (see below)

We developed our Flexicurve scaling metrics in a similar manner to that previously described [4] using half ($n = 57$) of the sample selected using random numbers. To create a scaling equation, linear regression was used with radiographic global Cobb angles as the outcome and inscribed Flexicurve kyphosis angles as the predictor. The beta coefficient and intercept were used in an equation to scale the inscribed Flexicurve kyphosis angles to equivalent radiographic global Cobb angles in the other half ($n = 60$) of the sample (radiographic global Cobb angle = intercept + (beta coefficient inscribed Flexicurve kyphosis angle). The linear regression procedure was repeated with vertebral centroid angles as the outcome in order to determine a separate equation for scaling inscribed Flexicurve kyphosis angles to equivalent vertebral centroid angles (vertebral centroid angle = intercept + (beta coefficient × inscribed Flexicurve kyphosis angle).

Descriptive statistics were calculated for participant characteristics and for the TK angles obtained using each method. Histograms for TK data obtained using each method were checked for outliers and normality. The mean difference (MD) and 95% confidence interval (CI) were calculated between all paired combinations of the measures, and these were compared using paired-samples t tests. A correlation matrix consisting of the TK data retrieved from each of the three methods was compiled to assess the strength, direction and significance of linear associations using Pearson product-moment correlation coefficients (r). Correlations were interpreted as weak ($r < 0.3$), moderate ($r = 0.3$–0.5) or strong ($r = > 0.5$) [27]. The criterion for statistical significance was set at $p < 0.05$.

Fig. 2 Radiographic thoracic kyphosis angles. a) Cobb angle where the angle formed is between intersecting lines drawn perpendicular to a line level with the superior endplate of T1 and inferior endplate of T12. b) Centroid angle formed between intersecting lines perpendicular to a line drawn with reference to the vertebral midpoints of T1 and T2 and line with reference to the midpoints of T11 and T12. Vertebral midpoints were located by digitising the upper right corner of the vertebral body and connecting this to the lower left corner using a diagonal line and repeating this for the upper left and lower right corners. The intersection of these lines represented the vertebral body midpoint
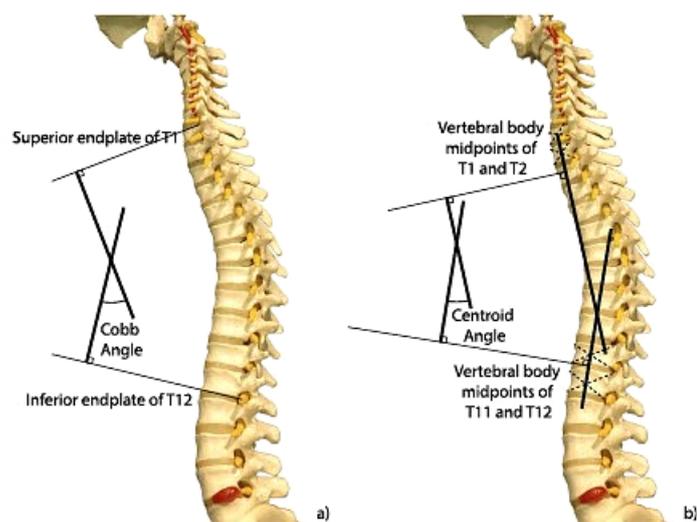
A Bland and Altman method was used to compare TK angles obtained using each method [28]. Flexicurve kyphosis angles scaled to respective global angles were paired with the radiographic Cobb and centroid angles and assessed for agreement by graphically plotting the differences between the measurements of each method for each participant (y-axis) against their mean (x-axis) [29]. A Bland and Altman plot between Flexicurve kyphosis angles scaled to constrained Cobb angles and radiographic Cobb angles was also compiled. The mean difference between the measurements of each method was represented in the Bland and Altman plot with a solid labelled line. Mean differences that deviated from zero indicated a bias [30]. The differences were checked for normality before calculating the 95% confidence intervals of the differences and adding these as the 95% limits of agreement in each plot. The scatter of differences were examined for uniformity around the mean and between the limits of agreement to determine if there was proportional bias and homoscedasticity of differences between measures [31].

Linear regression was used to assess if the differences in measurement between methods were predicted by age (years), BMI (kg/m^2) and BMD (g/cm^2).

Results

One hundred and seventeen postmenopausal women were included in these analyses. Participant characteristics are presented in Table 1. In 69 women, thoracic intervertebral osteoarthritis was absent or mild. The remaining 48 women showed moderate to severe thoracic intervertebral osteoarthritis. Seventeen women had radiological evidence of a vertebral fracture, five of these were located at T12. No vertebral fractures were identified at T1. For the assessment of radiographic angles, T12 was adequately visible in all cases and T1 was sufficiently visible in the majority of cases. For the assessment of Flexicurve angles, the scaling metrics used to convert Flexicurve kyphosis angles into equivalent global radiographic angles are summarised in Table 2.

There was no statistically significant difference between radiographic Cobb and vertebral centroid angles (MD 0.56°, 95%CI − 1.24° to 0.13°), and these methods shared the strongest correlation ($r = 0.94$, $p < 0.001$). Agreement between the radiographic methods was the strongest of all measures examined. A Bland and Altman plot of radiographic Cobb and vertebral centroid angles showed narrow limits of agreement (− 7.89° to 6.77°) and uniformity in the scatter of differences which were tightly clustered around zero (Fig. 3a).

Inscribed Flexicurve angles were the smallest TK angles overall and were significantly different from the angles produced by both the radiographic Cobb (MD 18.02°, 95%CI 16.35° to 19.69°) and vertebral centroid (MD 18.57°, 95%CI 16.99° to 20.17°) methods (Table 1). Correlations were, however, significant and strong between inscribed Flexicurve kyphosis angles and both Cobb ($r = 0.55$, $p < 0.001$) and vertebral centroid ($r = 0.61$, $p < 0.001$) angles.

Table 1 Participant characteristics

	n	Mean	SD	Minimum	Maximum
Age (years)	117	61.4	7.0	46.0	78.0
Height (cm)	117	161.3	6.2	145.8	170.0
Weight (kg)	117	75.3	15.3	42.1	127.2
Body mass index (kg/m^2)	117	29.0	5.5	18.0	47.0
Bone mineral density (femoral neck) (g/cm^2)[a]	115	0.9	0.1	0.6	1.2
Thoracic kyphosis					
Cobb angle method (°)	117	41.7	10.9	17.0	63.0
Cobb angle method (°)	60	40.9	11.3	17.0	63.0
Centroid angle method (°)	117	42.2	10.9	17.0	65.0
Centroid angle method (°)	60	41.7	11.3	17.0	65.0
Flexicurve angle (inscribed) method (°)	117	23.7	5.9	10.9	41.9
Flexicurve angle (scaled constrained Cobb) method (°)[b]	117	36.5	9.0	16.9	64.4
Flexicurve angle (scaled global Cobb) method (°)[c]	60	43.4	5.4	34.1	58.9
Flexicurve angle (scaled global centroid) method (°)[c]	60	43.8	6.6	32.5	62.9

[a] Two missing values

[b] Inscribed Flexicurve angles scaled using metrics created using hyperkyphotic women ($n = 80$) as described by Greendale et al. [4]

[c] Inscribed Flexicurve angles scaled using metrics created using random sample ($n = 57$) from this study

🖄 Springer

Table 2 Scaling metrics for converting inscribed Flexicurve kyphosis angles into global radiographic Cobb and vertebral centroid angles ($n = 57$)

Flexicurve kyphosis angle calculation method	Beta coefficient	Intercept	R^2
Flexicurve kyphosis angle (scaled global Cobb) method[a]	0.88	22.25	0.21
Flexicurve kyphosis angle (scaled global centroid) method[b]	1.07	17.98	0.31

[a] Metrics calculated from linear regression with global Cobb angle as outcome and inscribed Flexicurve kyphosis angle as predictor

[b] Metrics calculated from linear regression with vertebral centroid angle as outcome and inscribed Flexicurve kyphosis angle as predictor

Using Flexicurve data, scaled using our metrics for equivalent global radiographic angles, linear relationships were strengthened between Flexicurve kyphosis angles and radiographic Cobb ($r = 0.64$, $p < 0.001$) and vertebral centroid ($r = 0.66$, $p < 0.001$) angles. There was no statistically significant difference between vertebral centroid angles and Flexicurve kyphosis angles (scaled global centroid) (MD $- 2.16°$, 95%CI $- 4.35°$ to $0.03°$). In the Bland and Altman plot of these methods (Fig. 3b), limits of agreement were wide ($- 18.78°$ to $14.46°$). Proportional bias and heteroscedasticity (unequal variability) were also evident where the scatter in the accuracy of the scaled values increased as the amount of kyphosis increased but in a non-uniform manner.

There was a statistically significant difference between radiographic Cobb and Flexicurve kyphosis angles irrespective of whether global angle metrics or constrained angle metrics were used to scale the inscribed Flexicurve kyphosis angles.

For a constrained angle, correlations with radiographic Cobb angles were similarly strong ($r = 0.55$, $p < 0.001$), but the systematic error (MD $- 5.19°$, 95%CI $3.43°$ to $6.94°$) was higher than for an equivalent global angle (MD $2.48°$, 95%CI $- 4.77°$ to $- 0.19°$). In the Bland and Altman plot of radiographic Cobb and Flexicurve angles scaled to constrained angles (Fig. 3c), the limits of agreement were wide ($- 13.61°$ to $23.99°$) and the scatter of differences were non-uniform around the fixed bias of $5.19°$. Agreement between radiographic Cobb and Flexicurve kyphosis angles was improved in Bland and Altman plots where Flexicurve data were scaled to global angles (Fig. 3d). This was illustrated by lower fixed bias and narrower limits of agreement ($- 19.88°$ to $14.92°$). A proportional bias and mild heteroscedasticity was, however, more noticeable in this plot, where differences increased proportionally and non-uniformly as the average TK angle increased.

Fig. 3 a–d Plot of differences against averages for a) Cobb and centroid, b) vertebral centroid and Flexicurve (scaled global centroid), c) Cobb and Flexicurve (scaled constrained Cobb), and d) Cobb and Flexicurve (scaled global Cobb). Mean difference (solid line) and upper (+ 1.96SD) and lower (− 1.96SD) limits of agreement (dashed line) are shown
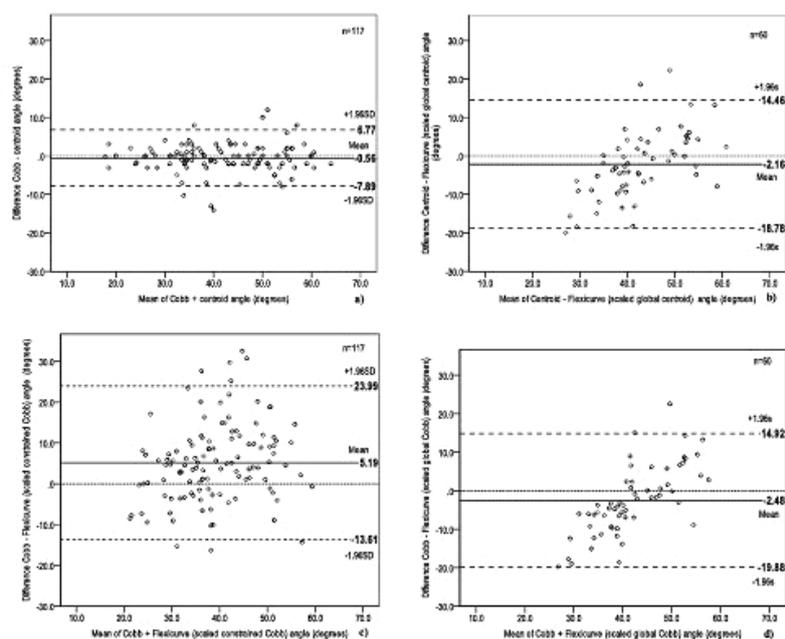
For the methods showing significant differences in TK angles, Table 3 shows which variables contributed to explaining these differences. Of the participant characteristics that were measured, age correlated positively with radiographic Cobb ($r = 0.20$, $p = 0.032$) and vertebral centroid ($r = 0.21$, $p = 0.025$) angles. In contrast, there was a negligible negative correlation with between age and inscribed ($r = -0.04$, $p = 0.691$) and scaled Flexicurve kyphosis angles, irrespective of whether global ($r = -0.02$, $p = 0.691$ ($n = 60$)) or constrained ($r = -0.02$, $p = 0.840$ ($n = 117$)) angle metrics were used. Age was a consistent significant predictor of the differences between inscribed Flexicurve angles and both the radiographic Cobb and centroid methods (Table 3). Age was also a significant predictor of the differences between radiographic Cobb and Flexicurve kyphosis angles when these were scaled to constrained Cobb angles (Table 3). The percentage of variance explained by age in each case was, however, small ($< 8\%$) (Table 3). Body mass index and BMD were not associated with the magnitude of the difference in TK in any of the methods of measurement (Table 3).

Discussion

In this study, we have identified that Flexicurve is unlikely to deliver accurate TK measurements because of the potential for sizeable differences between the TK angles determined using Flexicurve and those measured radiologically, regardless of whether the Cobb or centroid angles are used for comparison. Without scaling, Flexicurve consistently underestimates radiographic TK angles by around 18°, a magnitude that is similar to relevant previous accounts [4, 8]. This would be problematic in clinical contexts where excellent measures of TK are required. The process of scaling does reduce the systematic error of Flexicurve in producing an equivalent radiographic

angle, but this varies depending on the scaling method used and the degree of TK. Our data suggest that there is better accuracy in predicting vertebral centroid angles from scaled Flexicurve values but that this accuracy becomes more variable as the degree of TK increases. As a result, there should be caution around interpreting and using scaled Flexicurve kyphosis angles in postmenopausal women who have greater TK.

Several plausible reasons for the disparity in TK measures between Flexicurve and radiographic methods may be considered. First, the Flexicurve may be measuring angles that are fundamentally different to radiographic methods, and the discrepancies noted could reflect a true fault of the Flexicurve instrument. Second, there could be inherent problems in using radiographic Cobb angles to judge the validity of Flexicurve in older populations, and although the Cobb angle is consistently reported as the gold-standard, it may not be the most appropriate radiographic comparator to Flexicurve [32]. Third, the mathematical calculation used to determine Flexicurve kyphosis angles is clearly important, and the scaling metrics used with a geometric formula may be angle (Cobb versus centroid or global versus constrained) and population specific. Finally, participant-specific characteristics such as age, BMD and BMI may influence TK measurements differently [8, 14, 33], and confound comparisons between methods.

In our sample of postmenopausal women, we expected that the vertebral centroid method would be a preferable method to validate TK than the Cobb angle method and the results from our study partially support this. Unlike the vertebral centroid method, the Cobb method can be affected by regional deformities at T1 and T12 [14, 17, 32]. As a result, we hypothesised that there would be poorer agreement between Cobb and Flexicurve kyphosis angles than between vertebral centroid and Flexicurve kyphosis angles. With smaller non-significant systematic error and marginally narrower limits of agreement we observed a subtle improvement in the

Table 3 Predictor variables of the mean differences between methods

Predictor variable	Method comparison											
	Cobb-Flexicurve (inscribed)			Centroid-Flexicurve (inscribed)			Cobb-Flexicurve (scaled global Cobb)			Cobb-Flexicurve (scaled constrained Cobb)		
	$n = 117$			$n = 117$			$n = 60$			$n = 117$		
	R	R^2	p value	R	R^2	p value	r	R^2	p value	r	R^2	p value
Age	0.251	0.063	0.006	0.274	0.075	0.003	0.087	0.008	0.507	0.245	0.060	0.008
BMI	−0.030	0.001	0.749	0.001	0.000	0.992	−0.049	0.002	0.710	−0.063	0.004	0.502
BMD[a]	−0.076	0.006	0.419	−0.063	0.004	0.503	−0.156	0.024	0.242	−0.058	0.003	0.541

BMI body mass index, *BMD* bone mineral density

[a] Two missing values

capacity of Flexicurve to accurately estimate radiographic TK angles using the centroid over the Cobb method. In view of the random error in addition to the systematic error observed when producing equivalent vertebral centroid angles, however, the Flexicurve is still unlikely to be adequate for most clinical purposes. One factor that, in the current study, may have limited us from seeing a clear improvement in agreement between Flexicurve and vertebral centroid angles was the unexpected finding of a near perfect correlation and agreement between radiographic Cobb and vertebral centroid angles. Cobb angles did not appear to be inflated when compared to the vertebral centroid angles, as has been previously observed [14, 32]. In healthy postmenopausal women therefore, these appear to be comparable radiographic measures of TK.

An important finding of our study was the variability in errors that were introduced by using different methods for calculating the Flexicurve kyphosis angle. Previous literature has outlined the need to scale Flexicurve data before comparing it to radiographic angles [4] and we have clearly verified this by showing large systematic errors when inscribed Flexicurve data are used for comparison. We have, however, also highlighted the need for caution around applying scaling factors from one study to another. Scaling metrics suggested by Greendale et al. [4], which were explored as a method for scaling our Flexicurve data, did improve the approximation of Flexicurve kyphosis angles to radiographic Cobb angles by reducing the magnitude of systematic difference. However, despite this improvement, there was no change to the correlations with radiographic Cobb angles and there was still a statistically significant systematic error of $-5.19°$. This was greater than the error associated with using our own Flexicurve scaling metrics. Two important aspects of study design may explain why our own scaling metrics provided more accurate estimation of the radiographic angles. First, the formula developed by Greendale et al. [4] was derived from, and proposed for use in approximating, a constrained Cobb angle (T4–T12) which is expected to be lower than a global Cobb angle [4, 14, 18]. Second, the participants of their study were selected to have Cobb angles greater than 40°, so it is possible that the scaling metrics suggested were more specifically for use with participants with greater TK angles than ours.

In contrast to previous accounts [4, 8, 12], our findings show that discrepancies between Flexicurve and radiographic measures vary proportional to the angle being measured. This was evident when using Flexicurve data scaled using our own metrics and those that have been previously developed [4]. Using our scaled data, for example, Flexicurve was likely to underestimate radiographic angles in people with a normal TK ($<40°$) and this could be by as much as $-20°$. In people with hyperkyphosis ($>40°$), Flexicurve was more likely to overestimate radiographic angles, and this could be by as much as 15°. In addition, at greater TK angles, there appeared to be more variability in this pattern (heteroscedasticity) making the

Flexicurve a potentially more unpredictable tool for measuring TK in postmenopausal women with greater TK angles. Given that this was a subtle finding in our sample, further data from a more heterogeneous sample, including people with hyperkyphosis, are required to corroborate this. If confirmed, it is possible that a standardised scaling factor would not resolve the errors of Flexicurve in predicting abnormal ($>40°$) radiographic TK angles.

In addition to methodological reasons that may explain differences between Flexicurve kyphosis angles and radiographic angles, age, BMD and BMI were also characteristics that were explored. As expected, with such small differences between Flexicurve kyphosis (scaled global Cobb) angles and radiographic Cobb angles, these characteristics did not significantly explain any variance between these measures. Where differences were much larger, for example, between inscribed Flexicurve and radiographic angles, our linear regression established that age was the only characteristic to significantly predict these differences. Of interest was that this was also the case for the differences between radiographic methods and Flexicurve kyphosis angles scaled using the constrained Cobb metrics. In both cases, differences between Flexicurve and radiographic angles increased progressively with age, suggesting that the accuracy of Flexicurve decreases with increasing age using these two approaches. Increases in TK with age may explain this finding [1, 34]; however, our data showed a relatively weak positive correlation between age and radiographic angles to suggest otherwise. Furthermore, in contrast to radiographic angles, Flexicurve kyphosis angles were negatively correlated with age across the sample, regardless of scaling, which could also indicate that the differences with age are explained by the inaccuracies of the Flexicurve. Age accounted for less than 8% of the explained variability in TK between measures, so while this was significant, there are clearly other important factors that determine these differences. Of the other factors that we examined, neither BMI nor BMD were associated with the differences in angles between measures, indicating that these are not physical characteristics with appreciable influence. While every effort was made to ensure that methods were standardised in the present study, we cannot exclude that measurement and methodological factors, in addition to random error, were responsible for the remaining differences.

In summary, the new and novel finding of our study was that the vertebral centroid angle method was a distinguishably better radiographic comparator for the validation of Flexicurve. Although we were able to demonstrate that Flexicurve was better at producing equivalent radiographic vertebral centroid angles, we would still argue that the magnitude of systematic error is larger than ideal for most clinical purposes. Our findings also add to the body of evidence showing that Flexicurve and Cobb angles are related by strong correlation coefficients [4, 6–9, 12]. Our findings have,

93

however, confirmed previous research [8] in finding a lack of agreement between Flexicurve and Cobb angles, and in doing so, we highlight the limitations of using correlations to assume agreement. While the angles produced by Flexicurve may be conceptually similar to Cobb angles, they appear to be non-uniformly different.

A limitation of our study was that our Flexicurve method was based on a traditional technique where T12 was not formally identified on the Flexicurve at the time of measurement but instead was inferred as the end of the thoracic length from the tracing after measurement. This could be a possible source of error that may have resulted in over- or underestimating the thoracic length dimensions and the Flexicurve kyphosis angle itself. In addition, our Flexicurve kyphosis angles were calculated using one of several possible mathematical angle calculation methods and angles were scaled appropriately for our sample. The two scaling methods that have been compared in this study need further validation using samples with greater TK heterogeneity before deliberating whether Flexicurve is interchangeable with radiographic measures. With the discrepancies in scaled Flexicurve angles far exceeding the 3–11° measurement error associated with radiological methods alone [14, 15], stronger evidence is needed before using Flexicurve in clinical contexts where accurate measures of TK are required. Future studies might also investigate whether the agreement between Flexicurve and radiographic TK angles are improved by using alternative documented calculation methods [6, 10–12].

Although our findings have clearly outlined the limitations of Flexicurve, we acknowledge that there are some clinical circumstances where Flexicurve may still be considered a suitable surrogate measure of TK. In view of the strong correlations with radiographic measures and with Flexicurve measurements previously showing good intra- and inter-rater reliability [4–9], it may still be an appropriate method in clinical situations where the aim is to record change over time, but where the actual measurement is not a key factor. In this context, the benefits to the patient are a robust measure of change without the exposure to radiation.

Conclusion

TK measured in healthy postmenopausal women using the Flexicurve method shows better agreement with radiographic vertebral centroid angles than with radiological Cobb angles. Scaling Flexicurve data is helpful in improving the systematic error of Flexicurve in predicting vertebral centroid angles, but the inaccuracies of the Flexicurve appear to increase and become more variable with increasing angles of kyphosis. Caution is suggested when interpreting TK angles that are determined using the Flexicurve in postmenopausal women, particularly those with greater TK.

Compliance with ethical standards

All participants provided written informed consent. The study was approved by the Human Research Ethics Committee at Curtin University (RDHS-267-15).

Conflicts of interest None.

References

1. Fon GT, Pitt MJ, Thies AC Jr (1980) Thoracic kyphosis: range in normal subjects. Am J Roentgenol 134(5):979–983. https://doi.org/10.2214/ajr.134.5.979
2. Milne JS, Williamson J (1983) A longitudinal study of kyphosis in older people. Age Ageing 12(3):225–233
3. Puche RC, Morosano M, Masoni A, Jimeno NP, Bertoluzzo SM, Podadera JC, Podadera MA, Bocanera R, Tozzini R (1995) The natural history of kyphosis in postmenopausal women. Bone 17(3):239–246. https://doi.org/10.1016/8756-3282(95)00212-v
4. Greendale GA, Nili NS, Huang MH, Seeger L, Karlamangla AS (2011) The reliability and validity of three non-radiological measures of thoracic kyphosis and their relations to the standing radiological cobb angle. Osteoporos Int 22(6):1897–1905. https://doi.org/10.1007/s00198-010-1422-z
5. Fortin C, Feldman DE, Cheriet F, Labelle H (2011) Clinical methods for quantifying body segment posture: a literature review. Disabil Rehabil 33(5):367–383. https://doi.org/10.3109/09638288.2010.492066
6. Azadinia F, Kamyab M, Behtash H, Saleh Ganjavian M, Javaheri MR (2014) The validity and reliability of noninvasive methods for measuring kyphosis. J Spinal Disord Tech 27(6):E212–E218. https://doi.org/10.1097/BSD.0b013e31829a3574
7. Barrett E, McCreesh K, Lewis J (2014) Reliability and validity of non-radiographic methods of thoracic kyphosis measurement: a systematic review. Man Ther 19(1):10–17. https://doi.org/10.1016/j.math.2013.09.003
8. Barrett E, Lenehan B, O'Sullivan K, Lewis J, McCreesh K (2018) Validation of the manual inclinometer and flexicurve for the measurement of thoracic kyphosis. Physiother Theory Pract 34(4):301–308. https://doi.org/10.1080/09593985.2017.1394411
9. Tran TH, Wing D, Davis A, Bergstrom J, Schousboe JT, Nichols JF, Kado DM (2016) Correlations among four measures of thoracic kyphosis in older adults. Osteoporos Int 27(3):1255–1259. https://doi.org/10.1007/s00198-015-3368-7
10. Seidi F, Rajabi R, Ebrahimi I, Alizadeh MH, Minoonejad H (2014) The efficiency of corrective exercise interventions on thoracic hyper-kyphosis angle. J Back Musculoskelet Rehabil 27:7–16
11. Teixeira F, Carvalho GA (2007) Reliability and validity of thoracic kyphosis measurements using flexicurve method. Rev Bras Fis 11:199–204
12. de Oliveira TS, Candotti CT, La Torre M, Pelinson PP, Furlanetto TS, Kutchak FM, Loss JF (2012) Validity and reproducibility of the measurements obtained using the flexicurve instrument to evaluate the angles of thoracic and lumbar curvatures of the spine in the sagittal plane. Rehabil Res Pract 2012:186156. https://doi.org/10.1155/2012/186156
13. Raupp EG, Candotti CT, Marchetti BV, Vieira A, Medeiros FS, Loss JF (2017) The validity and reproducibility of the Flexicurve in the evaluation of cervical spine lordosis. J Manip Physiol Ther 40(7):501–510. https://doi.org/10.1016/j.jmpt.2017.06.010

14. Briggs A, Wrigley T, Tully E, Adams P, Greig A, Bennell K (2007) Radiographic measures of thoracic kyphosis in osteoporosis: cobb and vertebral centroid angles. Skelet Radiol 36(8):761–767. https://doi.org/10.1007/s00256-007-0284-8

15. Carman DL, Browne RH, Birch JG (1990) Measurement of scoliosis and kyphosis radiographs. Intraobserver and interobserver variation. J Bone Joint Surg 72(3):328–333

16. McAlister WH, Shackelford GD (1975) Measurement of spinal curvatures. Radiol Clin N Am 13:113–121

17. Lewis SJ, Dear TE, Zywiel MG, Keshen SG, Rampersaud YR, Magana SP (2016) T12 sagittal tilt predicts thoracic kyphosis. Spine Deform 4(2):112–119. https://doi.org/10.1016/j.jspd.2015.10.002

18. Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B (2001) Reliability of centroid, cobb, and Harrison posterior tangent methods: which to choose for analysis of thoracic kyphosis. Spine 26(11):E227–E234

19. Harrison DE, Harrison DD, Cailliet R, Janik TJ, Holland B (2001) Radiographic analysis of lumbar lordosis: centroid, cobb, TRALL, and Harrison posterior tangent methods. Spine 26(11):E235–E242

20. Chen YL (1999) Vertebral centroid measurement of lumbar lordosis compared with the cobb technique. Spine 24(17):1786–1790

21. Spencer L, Briffa K (2013) Breast size, thoracic kyphosis & thoracic spine pain - association & relevance of bra fitting in post-menopausal women: a correlational study. Chiropr Man Therap 21(20):1–8

22. Neumann DA (2010) Kinesiology of the musculoskeletal system: foundations for rehabilitation. Mosby/Elsevier, St. Louis

23. Thompson JC (2002) Netter's concise atlas of orthopaedic anatomy. Icon Learning Systems, Medimedia

24. Milne JS, Lauder IJ (1974) Age effects in kyphosis and lordosis in adults. Ann Hum Biol 1:327–337

25. Ettinger B, Black DM, Palermo L, Nevitt MC, Melnikoff S, Cummings SR (1994) Kyphosis in older women and its relation to back pain, disability and osteopenia: the study of osteoporotic fractures. Osteoporos Int 4:55–60

26. Griffith JF (2015) Identifying osteoporotic vertebral fracture. Quant Imaging Med Surg 5(4):592–602. https://doi.org/10.3978/j.issn.2223-4292.2015.08.01

27. Cohen J (1992) A power primer. Psychol Bull 112:155–159

28. Bland JM, Altman DG (1986) Statistical methods for assessing agreement between two methods of clinical measurement. Lancet 1(8476):307–310

29. Bland JM, Altman DG (1999) Measuring agreement in method comparison studies. Stat Methods Med Res 8(2):135–160. https://doi.org/10.1177/096228029900800204

30. Ludbrook J (1997) Comparing methods of measurements. Clin Exp Pharmacol Physiol 24(2):193–203

31. Ludbrook J (2010) Confidence in Altman-Bland plots: a critical review of the method of differences. Clin Exp Pharmacol Physiol 37(2):143–149. https://doi.org/10.1111/j.1440-1681.2009.05288.x

32. Alanay A, Pekmezci M, Karaeminogullari O, Acaroglu E, Yazici M, Cil A, Pijnenburg B, Genc Y, Oner FC (2007) Radiographic measurement of the sagittal plane deformity in patients with osteoporotic spinal fractures evaluation of intrinsic error. Eur Spine J 16(12):2126–2132. https://doi.org/10.1007/s00586-007-0474-z

33. Kado DM, Huang MH, Karlamangla AS, Cawthon P, Katzman W, Hillier TA, Ensrud K, Cummings SR (2013) Factors associated with kyphosis progression in older women: 15 years experience in the study of osteoporotic fractures. J Bone Miner Res 28(1):179–187. https://doi.org/10.1002/jbmr.1728

34. Milne JS, Lauder IJ (1976) The relationship of kyphosis to the shape of vertebral bodies. Ann Hum Biol 3:173–179

Attribution Statement							
Co-authored publication	**Conception, design and methodology**	**Implementation of the methodology and acquisition of data**	**Data analysis**	**Interpretation and discussion**	**Writing of original draft**	**Review and editing**	**Final approval**
Chapter 5. Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods							
Thesis Candidate: Linda Spencer	✓	✓	✓	✓	✓	✓	✓
Thesis Candidate Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 1: Dr Robyn Fary	✓			✓		✓	✓
Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 2: Dr Leanda McKenna	✓	✓		✓		✓	✓
Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 3: Dr Richard Ho		✓		✓			✓
Co Author 3 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 4: Dr Kathy Briffa	✓		✓	✓		✓	✓
Co Author 4 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Chapter 6 The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women.

The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women

Linda Spencer, Robyn Fary, Leanda McKenna,
Angela Jacques, Jennifer Lalor and Kathy Briffa

Abstract

Objectives: Increases in breast size with age are common but have not been widely examined as a factor that could affect the health and psychological wellbeing of mature-aged women. The purpose of this study was to examine the relationships between breast size and aspects of health and psychological wellbeing in mature-aged women.

Methods: This was a cross-sectional study of mature-aged women ($\geq$40 years). Breast size (breast size score) was determined from self-reported bra size and was examined against health-related quality of life (Medical Outcomes Study Short-Form 36 and BREAST-Q), body satisfaction (numerical rating scale), breast satisfaction (BREAST-Q), physical activity levels (Human Activity Profile), the presence of upper back pain and breast and bra fit perceptions.

Results: Two hundred sixty-nine women (40–85 years) with bra band sizes ranging from 8 to 26 and bra cup sizes from A to HH participated. The mean (standard deviation) breast size score of 7.7 (2.7) was equivalent to a bra size of 14DD. Increasing breast size was associated with significantly lower breast-related physical wellbeing ($p < 0.001$, $R^2 = 0.043$) and lower ratings of body ($p = 0.002$, $R^2 = 0.024$) and breast satisfaction ($p < 0.001$, $R^2 = 0.065$). Women with larger breasts were more likely to be embarrassed by their breasts (odds ratio: 1.49, 95% confidence interval: 1.31 to 1.70); more likely to desire a change in their breasts (odds ratio: 1.55, 95% confidence interval: 1.37 to 1.75) and less likely to be satisfied with their bra fit (odds ratio: 0.84, 95% confidence interval: 0.76 to 0.92). Breast size in addition to age contributed to explaining upper back pain. For each one-size increase in breast size score, women were 13% more likely to report the presence of upper back pain.

Conclusion: Larger breast sizes have a small but significant negative relationship with breast-related physical wellbeing, body and breast satisfaction. Larger breasts are associated with a greater likelihood of upper back pain. Clinicians considering ways to improve the health and psychological wellbeing of mature-aged women should be aware of these relationships.

Introduction

Good health and psychological wellbeing are attracting growing attention as desirable and closely related constructs that encompass more than simply the absence of illness and disease.[1] Physical, mental, social and behavioural aspects of these constructs together with the burden of any illness, injury, pain or disability are important considerations in the study of health and psychological wellbeing. Factors with the potential to affect directly or indirectly on the health and psychological wellbeing of mature-aged (middle age and older) women are important to identify, not least because these women represent an expanding proportion of the general Australian population[2] but also because with advancing

School of Physiotherapy and Exercise Science, Curtin University, Perth, WA, Australia

Corresponding author:
Linda Spencer, School of Physiotherapy and Exercise Science, Curtin University, GPO Box U1987, Perth, WA 6845, Australia.
Email: Linda.spencer@curtin.edu.au

age, health and psychological wellbeing become increasingly prominent and interdependent.[1]

The physical changes that affect a woman's body as a result of ageing have the potential to affect health and psychological wellbeing and should be considered more than inevitable changes. For many women, breasts contribute to their personal sense of attractiveness[3] and feminity[4] throughout their lifetime. The physiological changes that occur in breasts with ageing are well described[5-8] and are typically reported by women as an increase in breast size and ptosis.[4] Menopause is also a transitional period that influences a range of breast characteristics.[7] The increase in breast size[9] and the increase in the fat content of breasts[10] following menopause have been associated with increases in body weight around the same time.

Several qualitative studies have captured how the physical changes of breasts, with ageing, affect women.[3,4,11] The majority of mature women surveyed about these changes report being unhappy about them.[4] Up to 70% of older women report dissatisfaction with their breasts and the physical changes observed in breasts fuel this dissatisfaction.[3] Middle-aged women participating in a large survey study considered the physical changes in their breasts to be distressing and, together with the increases in body weight as they age, led to lower overall levels of body satisfaction and a reluctance to engage in physical activity.[11] Collectively, these studies provide some indication that the physical changes occurring in the breasts of women with age have wider implications. In addition to the discontentment and negative feelings these changes may arouse, they may also affect health and psychological wellbeing by perturbing important health behaviours such as physical activity. These findings of qualitative research have not yet been explored in quantitative research.

Increasing breast size, noted by women as they get older, may be particularly problematic for women's health and psychological wellbeing if the burden associated with large breasts that has been suggested in prior work is considered. Increased breast size has previously been related to reduced health and psychological wellbeing in studies of women undergoing reduction mammoplasty surgery where a range of negative physical[12-14] and psychological characteristics[13-22] have been attributed to having large or excessively large (hypertrophic) breasts. Characteristics that have been most widely examined and which show improvement following reduction mammoplasty include low quality of life,[16,17,19,21,23] body dissatisfaction,[15] low breast satisfaction,[16,19,24] depression,[18,20] upper back pain[14,25] and physical activity limitations.[25] The work undertaken in surgical studies suggests that these characteristics could be measurable aspects of health and psychological wellbeing related to larger breast sizes. However, these characteristics have had limited exploration in women not seeking reduction mammoplasty across a broad range of breast sizes.

Outside the reduction mammoplasty literature, there is growing evidence of the potential impact of larger breast sizes on aspects of physical health including perceptions of pain and physical activity. Pain felt in the thoracic spine[26,27] and upper back and torso[28,29] has been observed more commonly in women with large breasts across a range of ages who are not seeking reduction mammoplasty. Total time spent in physical activity and participation in vigorous physical activity have also been noted to be significantly lower among women (aged 18–75 years) with hypertrophic breasts compared to women with small breasts.[30] In addition, women with large breasts commonly cite their breast size as a barrier to physical activity participation.[30,31] With the health benefits of physical activity for mature-aged women well recognized,[32] but with only half of women at this age reported to be adequately active,[33] the negative impact of increasing breast size on physical activity levels could be an important burden on physical health that needs further consideration.

Consideration of body mass index (BMI) and bra-related factors that may also be a source of influence is necessary to progress understanding of the relationship between breast size and physical activity levels that may be particularly applicable to mature-aged women. Body size has been reported to have an important role in determining the physical activity levels of mature women[11] and this was alluded to, but not controlled for, in prior work that reported the negative trends in physical activity with increasing breast size.[30] In addition, the value of a correctly fitted bra may also be important to explore as a variable related to breast size affecting physical activity participation.[34-36] Mature-aged women with large breasts consider the comfort and fit of their bra as important,[4] and how satisfied they are with their bra fit may influence their willingness to participate in physical activity. Although women with large breasts commonly wear ill-fitting bras[27,37-40] and avoid having their bra professionally fitted,[38] it is unclear whether breast size per se contributes to these problems in mature-aged women.

To confirm whether increasing breast size has implications for health and psychological wellbeing in mature-aged women, the relationships between breast size and variables that reflect aspects of health and psychological wellbeing need to be more fully examined. In this study, we explored relationships between breast size and aspects of health and psychological wellbeing with the aim of identifying how increasing breast size may affect a woman in her mature years, while also examining the roles that age, BMI and menopausal status may have. The null hypothesis tested in this study was that larger breast sizes would not contribute to explaining negative changes in quality of life, body and breast satisfaction; physical activity levels and breast and bra fit perceptions; or the presence of upper back pain, beyond what can be explained by differences in age, menopausal status or BMI.

Table 1. Measured variables.

Variables	Type of variable	Measure
Predictors		
Breast size		
Breast size score	Continuous	Participant information questionnaire
Participant characteristics		
Age (years)	Continuous	Participant information questionnaire
Body mass index	Continuous	Participant information questionnaire
Menopausal status (premenopausal/postmenopausal)	Categorical	Participant information questionnaire
Outcomes		
Health-related quality of life		
Physical component summary score	Continuous	SF-36
Mental component summary score	Continuous	SF-36
Breast-related psychosocial wellbeing	Continuous	BREAST-Q
Breast-related physical wellbeing	Continuous	BREAST-Q
Satisfaction		
Body satisfaction	Continuous	Numerical rating scale
Breast satisfaction	Continuous	BREAST-Q
Physical activity		
Average physical activity levels	Continuous	Human Activity Profile
Upper back pain		
Upper back pain presence (yes/no)	Categorical	Participant information questionnaire
Breast and bra fit perceptions		
Breast embarrassment (yes/no)	Categorical	Participant information questionnaire
Desire to change breasts (yes/no)	Categorical	Participant information questionnaire
Professional bra fit (yes/no)	Categorical	Participant information questionnaire
Satisfaction with bra fit (yes/no)	Categorical	Participant information questionnaire

SF-36: Medical Outcomes Study Short-Form 36 Health Survey.

Methods

Participants

This was a cross-sectional questionnaire-based study conducted as part of a large project exploring the effects of increasing breast size on mature-aged women (defined as ⩾40 years). It was approved by the Human Research Ethics Committee at Curtin University (RDHS-267-15).

Participants were recruited via word-of-mouth and radio, newspaper and online advertising. Advertising was designed carefully to attract women of all breast sizes and minimize recruitment bias. Volunteers were excluded if they resided outside Australia; were unable to read and understand English; or were younger than 40 years. Volunteers were also excluded if they had undergone previous breast surgery or if they had a history of thoracic spine surgery, a systemic inflammatory condition, a neurodegenerative disorder or a known pathology of the breast, lung or thoracic spine or cancer involving the bones. Volunteers who had long-term and recent ongoing use of steroid or pain medication were also excluded for the purposes of an unbiased assessment of upper back pain within the larger project.

Procedure

Self-report data were collected using an online survey platform (Qualtrics, version June 2016, Provo, Utah, USA). The survey was made accessible electronically through a specifically designed study website or via an emailed URL link. Hard copies of the survey were available on request and returnable in a postage-paid envelope. The survey had a continuous structure and incorporated specifically designed questions (participant information questionnaire) and standardized questionnaires to assess breast size and the aspects of health and psychological wellbeing listed as outcome variables in Table 1. The survey had an estimated completion time of 20 min and participants indicated informed consent on the questionnaire. The survey flow function on electronic versions of the survey allowed customization of what a participant saw and which questions were asked based on the responses given. Complete answers were encouraged in electronic versions of the survey by imposing a forced response condition on all questions. Any questions left blank by respondents using paper formats of the survey were omitted and defined as a missing value.

Breast size. A breast size score (BSS), derived from participants' self-reported bra size, was used as a measure of breast

size. The BSS is an ordinal value (0–18) determined using numerical bra band sizes and alphabetical cup sizes (see Supplementary Material) which is similar in concept to the sizing system for unilateral breast prostheses[41] and has been used in prior research.[26,42] The BSS increments follow a numeric pattern, increasing sequentially relative to bra sizes, providing it with face validity. Using Australian bra sizes, a 14C is equivalent to a 12D or 16B; these each have a BSS of 6. A one-cup size increase (e.g. C to D) on the same band size (under bust, e.g. size 12) is equivalent to a 1-point increase in BSS. Alternatively, a one-band size increase (e.g. 12–14) with no change in cup size is also a 1-point increase in BSS.[42] In a subset of 119 participants,[42] BSSs derived from self-reported bra size data correlated significantly ($r=0.8$, $p<0.001$) with BSSs derived from investigator measured under and over bust circumferences.[43]

Participant characteristics. Participants' self-reported height and weight were used to calculate BMI (kg/m^2). Women were classified as postmenopausal if they had not menstruated in the past 12 months. Breast changes following menopause (not itemized in Table 1) were recorded in a multiple-choice question (as applicable) and answers were used for descriptive purposes only.

Health-related quality of life. The Medical Outcomes Study Short-Form 36 version 2.0 (SF-36) Health Survey[44,45] was used as a generic measure of health-related quality of life (HRQoL). This 36-item instrument comprises eight subscales: physical functioning (10 items); social functioning (2 items); role limitations due to physical problems (4 items); role limitations due to emotional problems (3 items); mental health (5 items); energy/vitality (4 items); bodily pain (2 items) and general health perceptions (5 items). A physical component summary score and mental component summary score were calculated according to the developer guidelines.[45]

In addition to this, a breast-specific measure was used to better characterize the impact of breasts on quality of life. The BREAST-Q (version 1.0 Reduction/mastopexy module)[46] is a patient-reported outcome measure that is used widely in breast-related research and can be administered at a single time-point in a cross-sectional survey to assess the breast-related themes.[46,47] Physical wellbeing and psychosocial wellbeing are two breast-related quality of life themes measured by BREAST-Q. Breast-related physical wellbeing (14 items) captures the physical problems caused by breast size, including pain; rashes; energy levels; and sleeping problems. Breast-related psychosocial wellbeing (9 items) captures the emotional problems caused by breast size including effects on self-esteem; confidence in social settings; and perceptions of body image. Stand-alone scores between 0 and 100 are generated for each theme, with higher scores indicating greater wellbeing.[48] The validity and reliability of the BREAST-Q in evaluating these constructs have been previously reported to be good.[46]

Satisfaction. A numerical rating scale (NRS) of body satisfaction was used as simple measure of body satisfaction. The NRS captured a single score between 0 (completely unsatisfied) and 10 (completely satisfied) in response to the question 'How satisfied are you with your body shape?' Similar numerical scales have been used in previous research on self-perceptions of mature women.[4]

Breast satisfaction was another breast-related theme that was measured using BREAST-Q. The breast satisfaction theme uses responses to 11 items that cover aspects of breast appearance clothed and unclothed, to give a score between 0 and 100 (higher scores indicating greater satisfaction) which can be used as a standalone scale.[46,48]

Physical activity levels. The Human Activity Profile,[49] a 94-item questionnaire that produces a score to indicate a participant's typical daily activity level (*adjusted activity score (AAS)*), was used to assess physical activity levels. Scores range from 0 to 94 with higher scores indicating higher average levels of activity.

Upper back pain. *Upper back pain* was assessed as present or not within the previous month (yes/no) to examine upper back pain prevalence.[50] Participants were provided with a body diagram where the upper back had been highlighted as the region above the base of the ribcage and below the neck.

Breast and bra fit perceptions. Closed questions of the participant information questionnaire asked whether participants were embarrassed about their breasts (yes/no); whether they would like to change their breasts (yes/no); whether they had their bra professionally fitted (yes/no); and whether they were satisfied with their bra fit (yes/no).

Data analysis

The sample size of 269 participants, determined for a concurrent study, was adequate to detect an odds ratio (OR) of 1.37 in any of the binary outcome variables (upper breast point (UBP) and breast and bra fit perceptions) and an R^2 of 0.011 in linear regression models fitting five covariates for continuous outcomes (HRQoL, satisfaction, physical activity) at 80% power, alpha=0.05.[51]

Associations between continuously measured predictors breast size and other relevant participant characteristics (age, BMI) with continuously measured outcome variables (HRQoL, satisfaction, physical activity) were initially examined using Pearson product-moment correlation coefficients (r).

The relationship between predictors (breast size, age, BMI and menopausal status) with each outcome variable was examined using multivariable linear and logistic regression models for continuous and categorical outcome

Table 2. Summary of participants' outcome data.

Outcome variable (possible score range)		*n*	Mean (SD)
Health-related quality of life			
Physical component summary score (0–100)		269	47.4 (8.5)
Mental component summary score (0–100)		269	51.1 (8.2)
Breast-related psychosocial wellbeing (0–100)		269	60.8 (20.2)
Breast-related physical wellbeing (0–100)		269	68.2 (14.3)
Satisfaction			
Body satisfaction (0–10)		268[a]	5.3 (2.4)
Breast satisfaction (0–100)		269	47.6 (17.7)
Physical activity			
Adjusted activity score (0–94)		269	71.5 (13.2)
Upper back pain			
Upper back pain presence	Yes	269	165 (61.0)
	No		104 (39.0)
Breast and bra fit perceptions			
Breast embarrassment	Yes	269	62 (23.0)
	No		207 (77.0)
Desire to change breasts	Yes	269	123 (46.0)
	No		146 (54.0)
Professional bra fit	Yes	267[b]	179 (67.0)
	No		90 (33.0)
Satisfaction with bra fit	Yes	267[b]	148 (55.0)
	No		119 (45.0)

SD: standard deviation.
[a]One missing value; [b] Two missing values.

variables, respectively. Results of linear regression models were reported as beta coefficients, corresponding 95% confidence intervals (CIs) and coefficients of determination (R^2) which explain proportion of variance attributable to predictors. Results of logistic regression models were reported as ORs and corresponding 95% CIs.

Model assumptions were checked (linearity, homoscedasticity, normality of residuals and multicollinearity), and sensitivity analyses were conducted, wherein outliers (z-residuals > 2.5) were identified and removed and the resulting model estimates compared against original estimates.

Data were analysed using SPSS version 24 (IBM; Chicago, IL), and statistical significance was set at $p < 0.05$.

Results

Two hundred and sixty-nine women between the ages of 40 and 85 years were recruited for this study. The mean (standard deviation (SD)) age, height, weight and BMI were 58.2 (9.1) years; 162.8 (7.1) cm; 73.3 (15.8) kg and 27.6 (5.6) kg/m², respectively. Bra band sizes ranged from 8 to 26 and bra cup sizes from A to HH. BSSs ranged from 2 to 16. The mean (SD) BSS of 7.7 (2.7) was equivalent to a bra size of 14DD. The majority (75%) of the sample were postmenopausal and of those, half (52%) reported a change in their breasts following menopause. An increase in size (61% of the participants)

and breast sensitivity (31% of participants) together with a change in breast shape (20% of participants) were the most common changes reported. Participants' outcome data are summarized in Table 2.

Correlations were interpreted as weak ($r < 0.3$), moderate ($r = 0.3–0.5$) or strong ($r > 0.5$).[52] Increasing BSS was strongly correlated with higher BMI ($p < 0.001$) and lower body satisfaction ($p < 0.001$; Table 3). Increasing breast size was moderately correlated with lower breast-related physical wellbeing ($p < 0.001$), lower physical component summary scores ($p < 0.001$), lower levels of breast-related psychosocial wellbeing ($p < 0.001$), lower breast satisfaction ($p < 0.001$) and lower levels of physical activity ($p < 0.001$; Table 3).

In addition, there were strong correlations between the following: physical activity and physical component summary scores ($r = 0.70$); breast-related psychosocial wellbeing and breast satisfaction ($r = 0.68$); and BMI and body satisfaction ($r = -0.58$; Table 3).

Breast size. Increasing BSS was significantly associated with lower breast-related physical wellbeing ($p < 0.001$, $R^2 = 0.043$), lower body satisfaction ($p = 0.002$, $R^2 = 0.024$), lower breast satisfaction ($p < 0.001$, $R^2 = 0.065$) and a higher odds of upper back pain ($p = 0.014$). For each one-size increase in BSS, participants were 13% more likely to report the presence of upper back pain. Increasing BSS was significantly associated with higher odds of breast

Table 3. Correlations between all variables measured on a continuous scale.

Pearson's product-moment correlation coefficients (r)

	Age	BMI	Physical component summary score	Mental component summary score	Breast-related psychosocial wellbeing	Breast-related physical wellbeing	Body satisfaction	Breast satisfaction	Physical activity (HAP)
Breast size (BSS)	0.099	0.753***	−0.393***	−0.093	−0.320***	−0.420***	−0.534***	−0.446***	−0.392***
Age (years)		0.082	−0.136**	0.182**	0.190**	0.115	0.048	0.110	−0.318***
BMI (kg/m²)			−0.475***	−0.108	−0.380***	−0.383***	−0.581***	−0.376***	−0.459***
Physical component summary score (SF-36)				0.211***	0.317***	0.566***	0.357***	0.338***	0.702***
Mental component summary score (SF-36)					0.452***	0.394***	0.287***	0.295***	0.196**
Breast-related psychosocial wellbeing (BREAST-Q)						0.555***	0.575***	0.679***	0.238***
Breast-related physical wellbeing (BREAST-Q)							0.426***	0.592***	0.445***
Body satisfaction (NRS)								0.566**	0.275***
Breast satisfaction (BREAST-Q)									0.288***

BSS: breast size score; BMI: body mass index; kg/m²: Kilogram per metre squared; SF-36: Medical Outcomes Study Short-Form-36 Health Survey; NRS: numerical rating scale; HAP: Human Activity Profile.
Correlations were interpreted as weak ($r < 0.3$), moderate ($r = 0.3–0.5$) or strong ($r > 0.5$).[50]
*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

embarrassment ($p \leqslant 0.001$) and a desire to change breasts ($p \leqslant 0.001$). For each one-size increase in BSS, participants were 49% more likely to be embarrassed by their breasts and 55% more likely to desire a change in their breasts. Participants with larger breasts were more likely to have their bra professionally fitted ($p = 0.002$) but were less likely to be satisfied with their bra fit ($p = 0.010$). For each one-size increase in BSS, participants were 27% more likely to have their bra professionally fitted but 16% less likely to be satisfied with their bra fit (Table 4).

Age. Increasing age was significantly associated with higher mental component summary scores ($p = 0.045$, $R^2 = 0.013$); higher breast-related psychosocial wellbeing ($p = 0.001$ $R^2 = 0.028$); higher breast-related physical wellbeing ($p = 0.027$, $R^2 = 0.010$); higher breast satisfaction ($p = 0.033$, $R^2 = 0.009$) and lower physical activity levels ($p < 0.001$, $R^2 = 0.043$). Increasing age was significantly associated with lower odds of upper back pain ($p < 0.001$) and breast embarrassment ($p = 0.031$). For each 1-year increment in age, participants were 5% less likely to report upper back pain and breast embarrassment (Table 4).

BMI. Increasing BMI was significantly associated with lower physical component summary scores ($p < 0.001$, $R^2 = 0.214$); lower breast-related psychosocial wellbeing ($p < 0.001$, $R^2 = 0.157$); lower body satisfaction ($p < 0.001$, $R^2 = 0.344$); and lower physical activity levels ($p < 0.001$, $R^2 = 0.188$). Participants with a higher BMI were less likely to have their bra professionally fitted ($p = 0.014$; Table 4).

Menopausal status. Menopausal status was not significantly associated with any of the outcome variables (Table 4).

Discussion

The findings of this study have confirmed that, in healthy mature-aged women, increasing breast size is negatively associated with a number of variables which may relate more broadly to their health and psychological wellbeing. Our results indicate that larger breast sizes are associated with small but important negative changes in breast-related physical wellbeing and lower ratings of body and breast satisfaction. In addition, our findings show that mature-aged women with larger breasts are significantly more embarrassed by the size of their breasts, are expressing a desire to change their breast size and are significantly less satisfied with their bra fit. This indicates, for the first time, that in mature-aged women, who are not seeking breast reduction, increasing breast size is negatively associated with aspects of psychological wellbeing. Our study also confirms the potential for increased breast size to affect physical health by showing that women with larger breast sizes are more likely to experience upper back pain, and this supports previous research examining mature-age women.[26,42] Ascertaining that breast size has a significant role in explaining negative changes in at least some of the aspects of health and psychological wellbeing that we have examined, allows us to partially reject our null hypothesis.

The quality of life of women with large breasts undergoing reduction mammoplasty has been well researched.[16,17,21,23,53–55] In women other than those with very large or hypertrophic breasts seeking reduction mammoplasty, there has been no direct examination of quality of life against differences in breast size. Our findings show that mature-aged women with larger breasts have significantly lower quality of life measured by both generic and breast-related measures. The correlations generated in our

Table 4. Relationships between predictors and outcomes: summary of multivariable regression models.

Outcome variable	n	Model components (linear regression) B (95% CI B)				Total model summary	
		Breast size	Age	BMI	Menopausal status	R^2	p value
Health-related quality of life							
Physical component summary score (SF-36)	269	-0.22 (-0.73 to 0.29)	-0.01 (-0.15 to 0.12)	-0.63 (-0.87 to -0.39)***	-2.36 (-5.16 to 0.44)	0.25^c	<0.001
Mental component summary score (SF-36)	269	-0.13 (-0.69 to 0.42)	0.15 (0.00 to 0.29)*	-0.14 (-0.40 to 0.13)	0.88 (-0.22 to 3.91)	0.05^c	0.008
Breast-related psychosocial wellbeing (BREAST-Q)	269	-0.73 (-1.97 to 0.52)	0.56 (0.23 to 0.88)**	-1.17 (-1.77 to -0.58)***	-1.64 (-8.48 to 5.19)	0.20	<0.001
Breast-related physical wellbeing (BREAST-Q)	269	-1.70 (-2.57 to -0.82)***	0.26 (0.03 to 0.49)*	-0.41 (-0.83 to 0.02)	-0.26 (-5.08 to 4.56)	0.21^c	<0.001
Satisfaction							
Body satisfaction (NRS)	269^b	-0.21 (-0.34 to -0.08)**	0.02 (-0.01 to 0.05)	-0.18 (-0.24 to -0.12)***	0.18 (-0.53 to 0.90)	0.37^a	<0.001
Breast satisfaction (BREAST-Q)	269	-2.56 (-3.63 to -1.50)***	0.31 (0.03 to 0.58)*	-0.30 (-0.82 to 0.21)	0.01 (-5.88 to 5.90)	0.23^c	<0.001
Physical activity							
Physical activity (HAP)	269	-0.40 (-1.16 to 0.37)	-0.37 (-0.57 to -0.17)***	-0.89 (-1.26 to -0.52)***	-1.29 (-5.51 to 2.92)	0.29^c	<0.001
		Model components (logistic regression) Odds ratio (95% CI)					
Upper back pain							
Upper back pain presence (yes/no)	269	1.13 (1.02 to 1.25)*	0.95 (0.92 to 0.98)***	1.03 (0.96 to 1.10)	1.20 (0.96 to 1.10)	0.09	<0.001
Breast and bra fit perceptions							
Breast embarrassment (yes/no)	269	1.49 (1.31 to 1.70)***	0.95 (0.91 to 0.98)*	1.02 (0.94 to 1.10)	0.93 (0.35 to 2.42)	0.25	<0.001
Desire to change breasts (yes/no)	269	1.55 (1.37 to 1.75)***	0.96 (0.93 to 1.01)	0.97 (0.90 to 1.04)	1.21 (0.51 to 2.87)	0.30	<0.001
Professional bra fit (yes/no)	267^b	1.27 (1.09 to 1.48)**	0.98 (0.95 to 1.02)	0.91 (0.85 to 0.98)*	0.77 (0.34 to 1.73)	0.05	0.006
Satisfaction with bra fit (yes/no)	267^b	0.84 (0.76 to 0.92)***	1.01 (0.97 to 1.05)	1.01 (0.94 to 1.08)	1.47 (0.67 to 3.22)^c	0.07	<0.001

B: beta coefficient; BMI: body mass index; SF-36: Medical Outcomes Study Short-Form 36 Health Survey; NRS: numerical rating scale; HAP: Human Activity Profile; CI: confidence interval.
^a One missing value; ^b Two missing values; ^c Sensitivity analysis completed and model unchanged by removing outlier(s).
*p < 0.05; **p < 0.01; and ***p < 0.001.

study confirm the notion of an inverse relationship between breast size and quality of life. However, we also acknowledge that for some aspects of quality of life, particularly those captured by generic measures, such as the SF-36, that differences in BMI, and to a lesser extent age, explain more than breast size and therefore look to be more important. The significant roles that advancing age and a higher BMI have in determining the HRQoL of mature-aged and older populations have been previously documented.[56,57] In agreement with these reports, our findings confirm that higher BMI, in particular, accounts for a considerable proportion of why mature-aged women perceive their physical health more negatively. In addition, although age and BMI have been identified as significant predictors in their own right, they are also clearly confounders for a range of HRQoL variables. As such age and BMI are important considerations for future work where the role of breast size on HRQoL is being examined.

The role of breast size was prominent in determining breast-related physical wellbeing. In contrast to the SF-36, this measure captures the specific physical problems caused by breast size, including pain, rashes, energy levels and sleeping problems.[48] Within our sample, breast size had a negative relationship with physical wellbeing which was slightly offset by the positive effects of age. This suggests that the burden of larger breasts is potentially problematic for the physical wellbeing of mature-aged women and that this may be in quite specific ways.

Prior qualitative research involving mature women has clearly stated that the breast changes occurring with age contribute to overall perceptions of body satisfaction.[4] Our findings add to this by confirming more specifically that increasing breast size is a significant contributor to lower ratings of body satisfaction in mature-aged women. In doing so, we speculate that there could be negative physical and psychological outcomes linked to this such as, the avoidance of physical activity,[11] anxiety,[58] depression,[59] and low self-esteem.[60]

It was expected that BMI would also be important in determining levels of body satisfaction in the participants of our study since prior qualitative work has reported the dominant role that body weight has in perceptions of body image in women of mature age.[11,61] Our findings confirm that increasing BMI is clearly related to lower body satisfaction, and the role of BMI in explaining variance in body satisfaction is substantial (34% of total variance). Of note, however, we have been able to distinguish that breast size is equally as important as BMI in the strength of its relationship with body satisfaction. This is notable because our results are drawn from a relatively simplistic measure of body satisfaction. Since the anthropometric data used in our study were also self-reported, future work may look to confirm the relationships we have identified between breast size and body satisfaction using objective measures of height, weight and breast size and a standardised measure of body satisfaction.

Breast satisfaction has been previously discussed as an important factor contributing to perceptions of attractiveness and body satisfaction in mature-aged women.[3,4] Beyond this, breast size has not been widely examined as a factor related to breast satisfaction that may affect the health and psychological wellbeing of mature-aged women. This has, however, been previously considered in research involving younger women (mean age 19 years)[62] and women seeking reduction mammoplasty.[63]

Our results have confirmed that breast size is clearly related to breast satisfaction in mature-aged women. Breast size had its strongest negative relationship with breast satisfaction. This was only slightly offset by increasing age but not by increasing BMI. The negative linear correlation between breast size and breast satisfaction that we measured confirms what is popularly assumed anecdotally, that women with large breasts are less satisfied with them. This is in contrast to what has been found among younger female populations where women with very small and very large breast sizes report lower breast satisfaction which indicates an inverted-U (Kuznets) curve relationship between breast size and breast satisfaction.[62]

Because increasing breast size is only one of a number of physical changes affecting breasts that may contribute to breast satisfaction in mature-aged women, we acknowledge that other factors, such as increasing ptosis,[3] may also be important. Our findings indicate that there is still a large proportion of the variance in breast satisfaction that remains unexplained by our predictors, and future work may examine other breast characteristics, such as ptosis, to explore this further.

Physical activity levels of mature-aged women are an important target for health-related research with the majority of middle-aged women being inadequately active,[33] despite the benefits of being well described.[32] We were unable to confirm that breast size is significantly associated with physical activity levels in mature-aged women after accounting for difference in age and BMI. We do, however, highlight that the negative pairwise correlation between breast size and physical activity levels reflects prior findings that women with larger breasts are typically less physically active.[30] Our results advance the understanding beyond what has already been described in prior research[30] by demonstrating that BMI, relative to breast size, is more important in determining physical activity levels.

Bra fit satisfaction also has relevance to physical activity levels. Our findings illustrate that mature-aged women are less likely to be satisfied with their bra fit as their breast size increases. Since satisfaction with bra fit in mature-aged women is likely to depend on how comfortable and well fitted they perceive their bra to be,[4] our results suggest that attaining a comfortable well-fitted bra is difficult for the women with larger breast sizes, despite it being more likely that they would have their bra professionally fitted. Exercise-induced breast discomfort as a result of an ill-fitting bra is a widespread problem among women with

large breasts[34-36] and a primary reason deterring them from participating in physical activity.[30,31] From the relationships that we have described, the full implications of an ill-fitting bra on the health and psychological wellbeing of mature-aged women warrants further investigation. As a factor that is amenable to change,[64] improving bra fit could be examined as a strategy to benefit health and psychological wellbeing by improving physical activity levels. The significant relationships identified between physical activity and HRQoL variables that we have reported (Table 3) suggest these benefits could be extensive.

Finally, by showing that women with larger breasts are more likely to experience upper back pain, we provide further evidence that upper back pain is a condition that is distinguishable as a physical health burden related to breast size. This has been previously suggested in prior research involving women who are seeking reduction mammoplasty[14,25,65] and also among women of varied age in general.[26,28,29,66] Our results highlight that an increase in breast size, equivalent to a one-cup size increase on the same band, or one-band size increase with the same cup size, leads to a 13% increase in the odds of upper back pain. A relatively small change in breast size, therefore, has the potential to effect health, and this effect remains after taking age into account. Since one in five women reports an increase in their bra size after menopause,[9] it is possible that upper back pain will be a problem for many mature-aged women. In the absence of prospective work on the topic, we cannot be certain about the scale of the increases in breast size with age nor that these occur independently of increases in body size around the same time.[8,9,67] Our findings have confirmed that larger breast size alone is sufficient to increase the odds for upper back pain; however, by not examining UBP severity in this study, we cannot be sure how bothersome this could be for mature-aged women. Low back pain deters physical activity participation[68] and reduces an individual's sense of mental and physical wellbeing.[69,70] Whether these low back pain findings are transferable to mature-aged women with upper back pain is an avenue for future research.

The results of our study should be considered in the context of its limitations. Our findings were generated from self-report data which are subject to issues of reporting accuracy. Breast sizes were calculated using participants' reported bra size, and it is acknowledged that most women wear an incorrectly fitted and sized bra.[26,27,38,40] In addition, bra sizes can differ across different brands and styles of bra.[71] These factors may have led to some underestimation or overestimation of actual breast size, but in the absence of more precise self-report measures, bra sizes were chosen as a suitable surrogate for breast size. The conversion of bra sizes into an ordinal BSS, while allowing us to rank participants breast sizes, requires further validation as a method to estimate actual breast size. Despite the limitations of the breast size scoring system, data that we have for a subset of our participants, in whom objective measures of bra size

were taken,[42] showed that BSSs determined from self-reported bra size were comparable to those scores determined using objective measures of bra size ($r=0.8$, $p<0.001$). This provided us with some confidence that the self-reported bra sizes of participants in the current study were a reasonable representation of their breast size. Finally, we note the limited ability of cross-sectional data in differentiating cause and effect. Further research is encouraged to confirm the nature and direction of the relationships that have been identified using objective measures of breast size and prospective study design.

In summary, the results of this study suggest that the burden of larger breasts in mature-aged women is subtly reflected in several aspects of health and psychological wellbeing. We have demonstrated that breast size has distinct, albeit small, negative relationships with breast-related physical wellbeing, ratings of body and breast satisfaction, as well as increasing the risk for upper back pain within the study population. Clinicians considering ways to improve the health and wellbeing of mature-aged women should be aware of these relationships.

ORCID iDs

Linda Spencer https://orcid.org/0000-0001-8744-3346
Kathy Briffa https://orcid.org/0000-0002-0731-4112

Supplemental material

Supplemental material for this article is available online.

References

1. Steptoe A, Deaton A and Stone AA. Subjective wellbeing, health, and ageing. *Lancet* 2015; 385(9968): 640–648.
2. Australian Bureau of Statistics. Population projections, Australia, 2012 (base) to 2101. Canberra, CT, Australia: Australian Bureau of Statistics (ABS), 2013.
3. Frederick DA, Peplau A and Lever J. The barbie mystique: satisfaction with breast size and shape across the lifespan. *Int J Sex Health* 2008; 20: 200–211.
4. Risius D, Thelwell R, Wagstaff CRD, et al. The influence of ageing on bra preferences and self-perception of breasts among mature women. *Eur J Ageing* 2014; 11(3): 233–240.

5. Checka CM, Chun JE, Schnabel FR, et al. The relationship of mammographic density and age: implications for breast cancer screening. *AJR Am J Roentgenol* 2012; 198(3): W292–W295.

6. Coltman CE, Steele JR and McGhee DE. Effect of aging on breast skin thickness and elasticity: implications for breast support. *Skin Res Technol* 2017; 23(3): 303–311.

7. Burton A, Maskarinec G, Perez-Gomez B, et al. Mammographic density and ageing: a collaborative pooled analysis of cross-sectional data from 22 countries worldwide. *PLoS Med* 2017; 14(6): e1002335.

8. Hammann-Kloss JS, Bick U, Fallenberg E, et al. Volumetric quantification of the effect of aging and hormone replacement therapy on breast composition from digital mammograms. *Eur J Radiol* 2014; 83(7): 1092–1097.

9. den Tonkelaar I, Peeters PH and van Noord PA. Increase in breast size after menopause: prevalence and determinants. *Maturitas* 2004; 48(1): 51–57.

10. Wanders JOP, Bakker MF, Veldhuis WB, et al. The effect of weight change on changes in breast density measures over menopause in a breast cancer screening cohort. *Breast Cancer Res* 2015; 17: 74–74.

11. McLaren L and Kuh D. Body dissatisfaction in midlife women. *J Women Aging* 2004; 16: 35–54.

12. Strong B and Hall-Findlay EJ. How does volume of resection relate to symptom relief for reduction mammaplasty patients. *Ann Plast Surg* 2015; 75(4): 376–382.

13. Reardon R and Grogan S. Women's reasons for seeking breast reduction: a qualitative investigation. *J Health Psychol* 2011; 16(1): 31–41.

14. Atterhem H, Holmner S and Janson PE. Reduction mammaplasty: symptoms, complications, and late results. *Scand J Plast Reconstr Surg Hand Surg* 1998; 32(3): 281–286.

15. Fonseca CC, Veiga DF, Garcia EDS, et al. Breast hypertrophy, reduction mammaplasty, and body image. *Aesthet Surg J* 2018; 38(9): 972–979.

16. Gonzalez MA, Glickman LT, Aladegbami B, et al. Quality of life after breast reduction surgery: a 10-year retrospective analysis using the Breast Q questionnaire: does breast size matter. *Ann Plast Surg* 2012; 69(4): 361–363.

17. Hermans BJ, Boeckx WD, De Lorenzi F, et al. Quality of life after breast reduction. *Ann Plast Surg* 2005; 55: 227–231.

18. Perez-Panzano E, Gascon-Catalan A, Sousa-Dominguez R, et al. Reduction mammaplasty improves levels of anxiety, depression and body image satisfaction in patients with symptomatic macromastia in the short and long term. *J Psychosom Obstet Gynaecol* 2017; 38(4): 268–275.

19. Cabral IV, da Silva Garcia E, Sobrinho RN, et al. Use of the BREAST-Q survey in the prospective evaluation of reduction mammaplasty outcomes. *Aesthetic Plast Surg* 2017; 42: 488–495.

20. Saariniemi KM, Joukamaa M, Raitasalo R, et al. Breast reduction alleviates depression and anxiety and restores self-esteem: a prospective randomised clinical trial. *Scand J Plast Reconstr Surg Hand Surg* 2009; 43(6): 320–324.

21. Saariniemi KM, Keranen UH, Salminen-Peltola PK, et al. Reduction mammaplasty is effective treatment according to two quality of life instruments. *J Plast Reconstr Aesthet Surg* 2008; 61(12): 1472–1478.

22. Berberoğlu Temel ÖM and Türkmen A. Effects of reduction mammaplasty operations on the spinal column: clinical and radiological response. *Aesthetic Plast Surg* 2015; 39: 514–522.

23. Perez-Panzano E, Guemes-Sanchez A and Gascon-Catalan A. Quality of life following symptomatic macromastia surgery: short- and long-term evaluation. *Breast J* 2016; 22(4): 397–406.

24. Coriddi M, Nadeau M, Taghizadeh M, et al. Analysis of satisfaction and well-being following breast reduction using a validated survey instrument: the BREAST-Q. *Plast Reconstr Surg* 2013; 132(2): 285–290.

25. Miller AP, Zacher JB, Berggren RB, et al. Breast reduction for symptomatic macromastia: can objective predictors for operative success be identified. *Plast Reconstr Surg* 1995; 95(1): 77–83.

26. Spencer L and Briffa K. Breast size, thoracic kyphosis & thoracic spine pain – association & relevance of bra fitting in post-menopausal women: a correlational study. *Chiropr Man Ther* 2013; 21: 1–8.

27. Wood K, Cameron M and Fitzgerald K. Breast size, bra fit and thoracic spine pain in young women: a correlational study. *Chiropr Osteopat* 2008; 16: 1340–1347.

28. McGhee D, Coltman KA, Riddiford-Harland DL, et al. Upper torso pain and musculoskeletal structure and function in women with and without large breasts: a cross sectional study. *Clin Biomech* 2018; 51: 99–104.

29. Coltman CE, Steele JR and McGhee DE. Can breast characteristics predict upper torso musculoskeletal pain? *Clin Biomech* 2018; 53: 46–53.

30. Coltman CE, Steele JR and McGhee DE. Does breast size affect how women participate in physical activity? *J Sci Med Sport* 2019; 22: 324–329.

31. Burnett E, White J and Scurr J. The influence of the breast on physical activity participation in females. *J Phys Act Health* 2015; 12(4): 588–594.

32. Mendoza N, De Teresa C, Cano A, et al. Benefits of physical exercise in postmenopausal women. *Maturitas* 2016; 93: 83–88.

33. Dontje ML, Krijnen WP, de Greef MH, et al. Effect of diagnosis with a chronic disease on physical activity behavior in middle-aged women. *Prev Med* 2016; 83: 56–62.

34. McGhee D, Steele J and Zealey W. Effects of high and low breast support on breast kinematics and kinetics during treadmill running. *J Sci Med Sport* 2010; 12: e143.

35. Risius D, Milligan A, Berns J, et al. Understanding key performance indicators for breast support: an analysis of breast support effects on biomechanical, physiological and subjective measures during running. *J Sports Sci* 2017; 35(9): 842–851.

36. White JL, Scurr JC and Smith NA. The effect of breast support on kinetics during overground running performance. *Ergonomics* 2009; 52(4): 492–498.

37. McGhee D and Steele JR. Optimising breast support in female patients through correct bra fit. *J Sci Med Sport* 2010; 13(6): 568–572.

38. Greenbaum AR, Heslop T, Morris J, et al. An investigation of the suitability of bra fit in women referred for reduction mammaplasty. *Br J Plast Surg* 2003; 56(3): 230–236.

39. White J and Scurr J. Evaluation of professional bra fitting criteria for bra selection and fitting in the UK. *Ergonomics* 2012; 55(6): 704–711.

40. Coltman CE, Steele JR and McGhee DE. Which bra components contribute to incorrect bra fit in women across a range of breast sizes? *Cloth Text Res J* 2017; 36: 78–90.

41. Ameona. Breast Form Fitting Guide, http://www.amoena.com/au/about-us/breast-form-fitting-guide/ (2017, accessed 31 August 2015).

42. Spencer L, McKenna L, Fary R, et al. Upper back pain in postmenopausal women and associated physical characteristics. *PLoS ONE* 2019; 14(7): e0220452.

43. Zheng R, Yu W and Fan J. 2 – Breast measurement and sizing. In: Yu W, Fan J, Harlock SC, et al. (eds) *Innovation and technology of women's intimate apparel*. Elsevier: Woodhead Publishing, 2006, pp. 28–58.

44. McCallum J. The SF-36 in an Australian sample: validating a new, generic health status measure. *Aust J Public Health* 1995; 19(2): 160–166.

45. Ware JE, Kosinski M and Dewey JE. *How to score version 2 of the SF-36 health survey*. Lincoln, RI: QualityMetric Incorporated, 2000.

46. Cano SJ, Klassen AF, Scott AM, et al. The BREAST-Q: further validation in independent clinical samples. *Plast Reconstr Surg* 2012; 129: 293–302.

47. Pusic AL, Klassen AF, Scott AM, et al. Development of a new patient-reported outcome measure for breast surgery: the BREAST-Q. *Plast Reconstr Surg* 2009; 124: 345–353.

48. Pusic AL, Cano SJ and Klassen AF. *BREAST-Q user manual 1.0.centre*. New York: MAPI Research Trust, Memorial Sloan-Kettering Cancer, 2012.

49. Fix A and Daughton D. *Human activity profile: professional manual*. Odessa, FL: Psychological Assessment Resources, 1988.

50. Briggs A, Bragge P, Smith AJ, et al. Prevalence and associated factors for thoracic spine pain in the adult working population: a literature review. *J Occup Health* 2009; 51(3): 177–192.

51. Faul F, Erdfelder E, Buchner A, et al. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. *Behav Res Methods 2009*; 41(4): 1149–1160.

52. Cohen J. A power primer. *Psychol Bull* 1992; 112: 155–159.

53. Saariniemi KM, Kuokkanen HO and Tukiainen EJ. The outcome of reduction mammaplasty remains stable at 2-5 years' follow-up: a prospective study. *J Plast Reconstr Aesthet Surg 2011*; 64(5): 573–576.

54. Hernanz F, Fidalgo M, Munoz P, et al. Impact of reduction mammoplasty on the quality of life of obese patients suffering from symptomatic macromastia: a descriptive cohort study. *J Plast Reconstr Aesthet Surg* 2016; 69(8): e168–e173.

55. Rogliani M, Gentile P, Labardi L, et al. Improvement of physical and psychological symptoms after breast reduction. *J Plast Reconstr Aesthet Surg* 2009; 62(12): 1647–1649.

56. Daviglus ML, Liu K, Yan LL, et al. Body mass index in middle age and health-related quality of life in older age: the Chicago heart association detection project in industry study. *Arch Intern Med* 2003; 163(20): 2448–2455.

57. Yan LL, Daviglus ML, Liu K, et al. BMI and health-related quality of life in adults 65 years and older. *Obes Res* 2004; 12(1): 69–76.

58. Barrett AE and Robbins C. The multiple sources of women's aging anxiety and their relationship with psychological distress. *J Aging Health* 2008; 20(1): 32–65.

59. Jackson KL, Janssen I, Appelhans BM, et al. Body image satisfaction and depression in midlife women: the Study of Women's Health Across the Nation (SWAN). *Arch Womens Ment Health* 2014; 17(3): 177–187.

60. Baker L and Gringart E. Body image and self-esteem in older adulthood. *Ageing Soc* 2009; 29: 977–995.

61. Runfola CD, Von Holle A, Peat CM, et al. Characteristics of women with body size satisfaction at midlife: results of the Gender and Body Image (GABI) study. *J Women Aging 2013*; 25(4): 287–304.

62. Koff E and Benavage A. Breast size perception and satisfaction, body image, and psychological functioning in Caucasian and Asian American college women. *Sex Roles* 1998; 38: 655–673.

63. Sarwer DB, Bartlett SP, Bucky LP, et al. Bigger is not always better: body image dissatisfaction in breast reduction and breast augmentation patients. *Plast Reconstr Surg* 1998; 101: 1956–1961.

64. McGhee D and Steele JR. Optimising breast support in female patients through correct bra fit: a cross-sectional study. *J Sci Med Sport* 2010; 13(6): 568–572.

65. Sigurdson L, Mykhalovskiy E, Kirkland SA, et al. Symptoms and related severity experienced by women with breast hypertrophy. *Plast Reconstr Surg* 2007; 119(2): 481–486.

66. Coltman CE, Steele JR and McGhee DE. Effect of breast size on upper torso musculoskeletal structure and function: a cross-sectional study. *Plast Reconstr Surg* 2019; 143(3): 686–695.

67. Coltman CE, Steele JR and McGhee DE. Breast volume is affected by body mass index but not age. *Ergonomics* 2017; 60: 1576–1585.

68. Schaller A, Exner A-K, Schroeer S, et al. Barriers to physical activity in low back pain patients following rehabilitation: a secondary analysis of a randomized controlled trial. *Biomed Res Int* 2017; 2017: 6925079.

69. Ludwig C, Luthy C, Allaz AF, et al. The impact of low back pain on health-related quality of life in old age: results from a survey of a large sample of Swiss elders living in the community. *Eur Spine J* 2018; 27(5): 1157–1165.

70. Husky MM, Ferdous Farin F, Compagnone P, et al. Chronic back pain and its association with quality of life in a large French population survey. *Health Qual Life Outcomes* 2018; 16(1): 195.

71. McGhee D and Steele JR. How do respiratory state and measurement method affect bra size calculations? *Br J Sports Med* 2006; 40(12): 970–974.

Breast Size Score (BSS) Conversion Chart[a]. Supplementary material for 'The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women'.

	Cup size	Band size (under-bust circumference, cm)									
		8 (63-67)	10 (68-72)	12 (73-77)	14 (78-82)	16 (88-87)	18 (88-92)	20 (93-97)	22 (98-102)	24 (103-107)	26 (108-112)
Breast size score (over-bust circumference, cm)	AA	0 (75-77)	1 (80-82)	2 (85-87)	3 (90-92)	4 (95-97)	5 (100-102)	6 (105-107)	7 (110-112)	8 (115-117)	9 (120-122)
	A	1 (77-79)	2 (82-84)	3 (87-89)	4 (92-94)	5 (97-99)	6 (102-104)	7 (107-109)	8 (112-114)	9 (117-119)	10 (122-124)
	B	2 (79-81)	3 (84-86)	4 (89-91)	5 (94-96)	6 (99-101)	7 (104-106)	8 (109-111)	9 (114-116)	10 (119-121)	11 (124-126)
	C	3 (81-83)	4 (86-88)	5 (91-93)	6 (96-98)	7 (101-103)	8 (106-108)	9 (111-113)	10 (116-118)	11 (121-123)	12 (126-128)
	D	4 (83-85)	5 (88-90)	6 (93-95)	7 (98-100)	8 (103-105)	9 (108-110)	10 (113-115)	11 (118-120)	12 (123-125)	13 (128-130)
	DD	5 (85-87)	6 (90-92)	7 (95-97)	8 (100-102)	9 (105-107)	10 (110-112)	11 (115-117)	12 (120-122)	13 (125-127)	14 (130-132)
	E	6 (87-89)	7 (92-94)	8 (97-99)	9 (102-104)	10 (107-109)	11 (112-114)	12 (117-119)	13 (122-124)	14 (127-129)	15 (132-134)
	F	7 (89-91)	8 (94-96)	9 (99-101)	10 (104-106)	11 (109-111)	12 (114-116)	13 (119-121)	14 (124-126)	15 (129-131)	16 (134-136)
	G	8 (91-93)	9 (96-98)	10 (101-103)	11 (106-108)	12 (111-113)	13 (116-118)	14 (121-123)	15 (126-128)	16 (131-133)	17 (136-138)
	H	9 (93-95)	10 (98-100)	11 (103-105)	12 (108-110)	13 (113-115)	14 (118-120)	15 (123-125)	16 (128-130)	17 (133-135)	18 (138-140)

[a] To determine a breast size score first identify the correct bra size (band and cup size). Establish the correct band size by measuring around the body, directly below the bust (under-bust circumference) and the correct cup size by measuring across the fullest part of the breasts whilst wearing a bra (over-bust circumference)[1]. Use the top row of the table to select the band size, this increases from left to right. Then use the first column of the table to select the cup size, this increases from top to bottom. Track down and across to find the table cell where these two selections intersect. Breast size score is shown in bolded text.

References
[1] Berlei. Australian Bra Sizes: Berlei; 2018 [January 2018]. Available from: https://www.berlei.com.au/size-charts

Attribution Statement							
Co-authored publication	**Conception, design and methodology**	**Implementation of the methodology and acquisition of data**	**Data analysis**	**Interpretation and discussion**	**Writing of original draft**	**Review and editing**	**Final approval**
Chapter 6. The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women.							
Thesis Candidate: **Linda Spencer**	✓	✓	✓	✓	✓	✓	✓
Thesis Candidate Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 1: Dr Robyn Fary	✓			✓		✓	✓
Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 2: Dr Leanda McKenna	✓			✓		✓	✓
Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 3: Ms Angela Jacques			✓				✓
Co Author 3 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 4: Dr Jennifer Lalor			✓				✓
Co Author 4 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 5: Dr Kathy Briffa	✓		✓	✓		✓	✓
Co Author 5 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Chapter 7 Upper back pain, health and psychological wellbeing

7.1 Abstract

Objectives: The self-report characteristics associated with upper back pain (UBP) have not been widely-examined but may reflect aspects of health and psychological wellbeing that are related to UBP independent of breast size. This chapter examines aspects of health and psychological wellbeing, measured as self-report characteristics, against the presence and severity of UBP. The aim of this chapter was to identify those characteristics associated with the presence and severity of UBP that were independent of breast size.

Methods: The presence (within the previous month) and severity (Numerical Rating Scale, NRS) of UBP were examined against: height, weight, BMI, menopausal status, employment status, physical activity levels (Human Activity Profile), health-related quality of life (HRQoL) (Medical Outcomes Study Short Form-36 Health Survey (SF-36) and BREAST-Q), body satisfaction (NRS), and breast satisfaction (BREAST-Q). A multivariable logistic regression model adjusted for age and breast size (bra size) was built using self-report characteristics with a significant univariate association with UBP. Censored Tobit regression, adjusted for age and breast size, was used to examine each physical characteristic against UBP severity.

Results: The data of 269 mature-aged women with a mean (SD) age of 58.2 (9.1) years were analysed. After adjusting for age and breast size, the self-report characteristics independently associated with UBP were SF-36 physical component summary (PCS) scores and breast satisfaction. Higher SF-36 PCS scores (OR: 0.41, 95%CI: 0.28 to 0.59) and greater breast satisfaction (OR: 0.53, 95%CI: 0.37 to 0.76) were both associated with lower odds for UBP. This model explained 30% of the variance in UBP presence (p<0.001). After adjusting for age and breast size, differences in UBP severity were also explained by SF-36 PCS scores and breast satisfaction. Higher SF-36 PCS (Tobit regression coefficient: -1.27, 95%CI:-1.58 to -0.95) scores and greater breast satisfaction (Tobit regression coefficient:-0.85, 95%CI: -1.20 to -0.51) scores were associated with lower severities of UBP.

Conclusion: SF-36 PCS scores and breast satisfaction are characteristics associated with the presence and severity of UBP that reflect UBP's multi-dimensional nature and that may be worth considering clinically.

7.2 Introduction

Aspects of health and psychological wellbeing associated with UBP in mature-aged women have not been extensively examined[2]. In this chapter the variables of self-reported physical activity, HRQoL, and breast and body satisfaction are examined against the presence and severity of UBP. In Chapter 6, these variables were aspects of health and psychological wellbeing shown to correlate negatively with increasing breast size. Breast size had an independent association with a number of these characteristics to suggest that larger breast sizes may negatively affect the health and psychological wellbeing of mature-aged women. Since UBP is more likely in women with larger breasts (Chapter 6), it is conceivable that differences in physical activity, HRQoL and breast and body satisfaction may relate to UBP in addition to breast size. What has been viewed as a negative consequence of breast size may equally reflect a burden of UBP. In a reciprocal relationship, these self-report variables may also contribute to the UBP experience independently of breast size. It is possible that there could be some self-report characteristics that are protective against UBP or alternatively there may be some that are targetable risk factors distinct from breast size. With the aim of progressing understanding of the nature of the relationship between breast size and UBP, this chapter examines the self-report characteristics associated with UBP whilst controlling for the effects of breast size. The null hypothesis to be tested was that physical activity, HRQoL, and body and breast satisfaction would have no meaningful associations with UBP that were independent of breast size.

7.3 Methods

For this chapter, the cross-sectional survey data of mature-aged women (aged $\geq$ 40 years) with and without UBP (community-based sample) were used. Recruitment (section 2.2.1), exclusion criteria (section 2.2.4) and procedures (section 2.3) are described fully in prior chapters.

Self-report data including: participants' age, breast size (refer to section 2.4.3), height (refer to section 2.4.1), weight (refer to 2.4.1), menopausal status (refer to section 2.4.1), employment status (refer to section 2.4.1), physical activity levels (refer to section 2.4.4), HRQoL (SF-36 PCS and SF-36 MCS scores and breast-related psychosocial wellbeing) (refer to section 2.4.5), body satisfaction (refer to section 2.4.6), and breast satisfaction (refer to section 2.4.3) were analysed.

For the purposes of this chapter, UBP was examined as the dependent variable. As a dichotomous categorical variable UBP was assessed as either being present or not (yes/no).

As a continuous variable UBP was rated using a severity score (NRS) of between 0 (no pain) and 10 (worst pain imaginable) (refer to section 2.4.2).

7.4 Statistical analysis

Data were analysed using SPSS version 24 (IBM; Chicago, IL) and STATA version 15.1 (StatCorp LP, College station, TX). Descriptive statistics were calculated for all participant characteristics. Participants were divided into two groups; one group with UBP and one group without UBP based on survey responses. Statistical significance level was set at $p<0.05$.

Each self-report characteristic was evaluated separately in a logistic regression model for the dichotomous dependent variable of UBP (yes/no). Odds ratios were standardised by calculating them for a one standard deviation change in each variable. Each characteristic was then evaluated separately in a logistic regression model adjusted for 1) age and 2) age and breast size. The assumptions of each model were checked and residual diagnostics were examined. Sensitivity analysis was conducted where outliers were identified.

A multivariable model, adjusted for age in step one and breast size in step two, was built to determine the explained variance in UBP (yes/no) independent of differences in age and breast size. Those characteristics significantly associated with UBP (yes/no) independent of age and breast size were entered as z-scores into the multivariable model with probability of removal of $p=0.05$. The assumptions of the model were scrutinised and sensitivity analysis completed as required. Variation inflation factors (VIFs >10) and tolerance (<0.1) were used to judge collinearity between variables in the model. The total variance in UBP (yes/no) explained by the model (Nagelkerke R^2), and characteristics with a statistically significant contribution, were determined and standardised odds ratios (95%CI) were estimated.

Censored regression (Tobit model) analysis was used to assess univariate linear relationships between each continuous self-report characteristic and UBP severity (NRS) as NRS data were left-censored. This was repeated with adjustment for 1) age and 2) age and breast size. A hierarchical Tobit regression model, adjusted in step one for age and step two for breast size, was built using those characteristics that were significantly associated with UBP severity independent of age and breast size. Those characteristics with a statistically significant contribution to the final model were identified.

7.5 Results

Data of 269 participants were analysed (Table 7.1). One hundred and sixty-five (57%) participants reported UBP and were included in the UBP group. The majority (92%) of these participants had chronic UBP (>3month duration). The mean (SD) NRS score for participants with UBP was 4.5 (2.1) with 58 (35%) rating UBP as mild (NRS≤3), 77 (47%) as moderate (NRS 4-6), and 30 (18%) as severe (NRS≥7). Approximately half (59%) of participants in the study were in full or part-time employment.

Table 7.1 Descriptive summary

Self-report characteristic	n	Mean (SD)
Participant characteristics		
Age (yrs)	269	58.2 (9.1)
Breast size (BSS)	269	7.7 (2.7)
Height (cm)	269	162.8 (7.1)
Weight (kg)	269	73.3 (15.8)
BMI (kg/m²)	269	27.6 (5.6)
Physical activity		
Physical activity levels (HAP AAS 0-94)	269	71.5 (13.2)
Health-related quality of life		
Physical component summary (SF-36 PCS score 0-100)	269	47.4 (8.5)
Mental component summary (SF-36 MCS score 0-100)	269	51.1 (8.2)
Breast-related psychosocial wellbeing (BREAST-Q score 0-100)	269	60.8 (20.2)
Satisfaction		
Body satisfaction (NRS 0-10)	268[a]	5.3 (2.4)
Breast satisfaction (BREAST-Q score 0-100)	269	47.6 (17.7)

[a] One missing value. **Abbreviations:** yrs – Years; BSS – Breast size score; cm – Centimetres; kg – Kilograms; kg/m² - Kilograms per metre-squared; HAP - Human Activity Profile; AAS – Adjusted activity score; SF-36 – Medical Outcomes Study Short-Form 36 Health Survey; PCS – Physical component summary; MCS – Mental component summary; NRS – Numerical Rating Scale; SD – Standard deviation.

Preliminary analysis of between-group differences in participant characteristics identified that participants with UBP were significantly younger (MD: -3.9 years, 95%CI: -6.1 to -1.7 years), had larger breasts (MD: 0.7 sizes, 95%CI: 0.04 to 1.4 sizes), and were more likely to be pre or peri-menopausal than participants without UBP (Table 7.2). Participants with larger breasts and a greater BMI were significantly more likely to experience UBP after accounting for differences in age (Table 7.2).

7.5.1 Physical activity

Participants with UBP were significantly less active than participants without UBP (MD: -4.4, 95%CI: -7.7 to -1.2). The odds for UBP were lower in participants with higher physical activity levels and this remained the case after adjustment for 1) age and 2) age and breast size (Table 7.2).

7.5.2 Health-related quality of life

Participants with UBP recorded lower HRQoL than participants without UBP, reflected in SF-36 PCS scores (MD: -5.7, 95%CI: -3.7 to -7.7), SF-36 MCS scores (MD: -2.4, 95%CI: -0.3 to -4.4), and breast-related psychosocial wellbeing (BREAST-Q) (MD: -11.9, 95%CI: -7.1 to -16.6). The relationship between UBP and SF-36 PCS scores and between UBP and breast-related psychosocial wellbeing were independent of 1) age and 2) age and breast size (Table 7.2).

7.5.3 Satisfaction

Participants with UBP had significantly lower body satisfaction (MD: -1.3, 95%CI: -0.7 to -1.9) and breast satisfaction (MD: -11.8, 95%CI: -15.9 to -7.6) and these relationships were independent of 1) age and 2) age and breast size (Table 7.2).

7.5.4 Upper back pain risk: final model

Variables entered into the multivariable model adjusted for age and breast size were: height, breast satisfaction, physical activity level, SF-36 PCS scores, breast-related psychosocial wellbeing, and body satisfaction. The model was statistically significant X^2 (4) = 66.19, p<0.001 and explained 30% (Nagelkerke R^2) of the variance in UBP. Of the eight predictor variables entered into the multivariable model, age, SF-36 PCS scores and breast satisfaction were statistically significant (Table 7.2).

7.5.5 Upper back pain severity

There were significant but small reductions in UBP severity scores for each respective standard deviation unit increase in: physical activity level, SF-36 PCS score, SF-36 MCS score, breast-related psychosocial wellbeing, breast satisfaction, and body satisfaction (Table 7.3). In the multivariable Tobit model adjusted for age and breast size and containing these significant characteristics, those with a significant contribution to the final model were age (p=0.001), SF-36 PCS scores (p=<0.001), and breast satisfaction (p=0.001) (Table 7.3). Upper back pain severity reduced by an NRS score of 1.1 for each standard deviation (8.5) unit increase in SF-36 PCS score, and by 0.6 for each standard deviation (17.7) unit increase in breast satisfaction score (Table 7.3).

Table 7.2 Logistic regression analysis: self-report characteristics and the association with UBP (yes/no)

Self-report characteristic		UBP (n=165) Mean (SD)	Nil UBP (n=104) Mean (SD)	Univariate analysis Odds ratio (95%CI)	p-value	Step 1 Adjustment for age Odds ratio (95%CI)	p-value	Step 2 Adjustment for age & breast size Odds ratio (95%CI)	p-value	Final model[c] step1: age Step 2: breast size Step 3: predictor variables Odds ratio (95%CI)	p-value
Participant characteristics											
Age (yrs)		56.7 (9.0)	60.6 (8.8)	**0.64 (0.49-0.80)**	**0.001**	-	-	-	-	**0.55 (0.41-0.74)**	**<0.001**
Breast size (BSS)		8.0 (2.7)	7.3 (2.7)	**1.31 (1.01-1.68)**	**0.039**	**2.42 (1.22-4.75)**	**0.004**	-	-	0.79 (0.56-1.35)	0.174[d]
Height (cm)		162.3 (7.0)	163.5 (7.0)	0.85 (0.66-1.08)	0.188	0.78 (0.60-1.01)	0.064	**0.75 (0.58-0.98)**	**0.032**		0.329[d]
Weight (kg)		74.3 (16.1)	71.7 (15.4)	1.19 (0.92-1.53)	0.179	1.21 (0.93-1.56)	0.150	0.89 (0.61-1.31)	0.555		
BMI (kg/m²)		28.2 (5.7)	26.8 (5.3)	1.30 (1.00-1.68)	0.050	**1.37 (1.05-1.79)**	**0.022**	1.15 (0.78-1.72)	0.470		
Menopausal status	Pre-peri	49 (30.0)[a]	17 (16.3)[a]	**0.72 (0.55-0.94)**	**0.014**	1.15 (0.51-2.58)	0.740	1.20 (0.53-2.74)	0.657		
	Post	116 (70.0)[a]	87 (83.7)[a]								
Employment	Yes	103 (62.4)[a]	55 (52.8)[a]	1.22 (0.95-1.55	0.122	0.73 (0.71-1.28)	0.732	1.05 (0.57-1.93)	0.885		
	No	62 (37.6)[a]	49 (47.2)[a]								
Physical activity											
Adjusted activity score (HAP AAS)		69.8 (14.1)	74.3 (11.4)	**0.70 (0.54-0.91)**	**0.008**	**0.53 (0.38-0.73)[c]**	**<0.001**	**0.56 (0.40-0.79)[c]**	**0.001**		0.719[d]
Health-related quality of life											
Physical component summary (PCS) scores (SF-36)		45.2 (8.5)	50.9 (7.3)	**0.44 (0.32-0.60)[c]**	**<0.001**	**0.37 (0.26-0.52)[c]**	**<0.001**	**0.37 (0.25-0.53)[c]**	**<0.001**	**0.41 (0.28-0.59)**	**<0.001**
Mental component summary (MCS) scores (SF-36)		50.1 (8.1)	52.5 (8.2)	**0.74 (0.57-0.96)**	**0.024**	0.80 (0.61-1.04)	0.090	0.82 (0.63-1.08)	0.155		
Breast-related psychosocial wellbeing (BREAST-Q)		56.2 (20.0)	68.1 (18.2)	**0.53 (0.41-0.70)**	**<0.001**	**0.56 (0.42-0.74)**	**<0.001**	**0.59 (0.44-0.79)**	**<0.001**		0.733[d]
Satisfaction											
Body satisfaction (NRS)[b]		4.8 (2.4)	6.1 (2.1)	**0.56 (0.43-0.73)**	**<0.001**	**0.55 (0.42-0.73)[c]**	**<0.001**	**0.56 (0.40-0.77)[c]**	**<0.001**		0.181[d]
Breast satisfaction (BREAST-Q)		43.0 (16.7)	54.8 (16.8)	**0.46 (0.34-0.63)**	**<0.001**	**0.46 (0.34-0.63)**	**<0.001**	**0.47 (0.33-0.66)**	**<0.001**	**0.53 (0.37-0.76)**	**0.001**

[a] Categorical variable presented as n (%); [b] one missing value; [c] ≤3 outliers (z-residuals>2.5) remained in the analysis; [d] variable removed in final model (p<0.05); Bolded figures – p<0.05;
Abbreviations: UBP - Upper back pain; BSS - Breast size score; pre-peri – pre or perimenopausal; HAP AAS - Human Activity Profile adjusted activity score; SF-36 – Medical Outcomes Study Short-Form-36 Health Survey; PCS - Physical component summary; MCS - Mental component summary; NRS - Numerical rating scale; SD - Standard deviation; CI - Confidence interval; yrs – Years; cm – Centimetres; kg – Kilograms; kg/m² – Kilograms per metre-squared.

Table 7.3 Censored (Tobit) regression analysis: self-report characteristics and the association with UBP severity (NRS)

Self-report characteristic	Tobit model regression UBP (NRS)							
	Univariate analysis		Step 1: Adjustment for age		Step 2: Adjustment for age & breast size		Multivariable analysis Step 1: age Step 2: breast size Step 3: predictor variables	
	Tobit regression coefficient (95%CI)	p-value	Tobit regression coefficient (95%CI)	p-value	Tobit regression coefficient (95%CI)	p-value	Tobit regression coefficient (95%CI)	p-value
Participant characteristics								
Age (yrs)	**-0.43 (-0.75 to -0.10)**	**0.010**	-	-	-	-	**-0.50 (-0.79 to -0.21)**	**0.001**
Breast size (BSS)	**0.46 (0.14 to 0.78)**	**0.006**	-	-	-	-	-0.20 (-0.53 to 0.13)	0.274[b]
Height (cm)	-0.26 (-0.59 to 0.07)	0.122	-0.32 (-0.65 to 0.00)	0.053	**-0.38 (-0.70 to -0.06)**	**0.020**		0.315
Weight (kg)	0.24 (-0.09 to 0.57)	0.149	0.25 (-0.07 to 0.57)	0.131	-0.28 (-0.76 to 0.19))	0.243		
BMI (kg/m^2)	**0.36 (0.04 to 0.69)**	**0.029**	**0.40 (0.08 to 0.72)**	**0.015**	0.05 (-0.44 to 0.53)	0.847		
Physical activity								
Adjusted activity score (HAP AAS)	**-0.80 (-1.12 to -0.49)**	**<0.001**	**-1.04 (-1.36 to-0.72)**	**<0.001**	**-0.98 (-1.33 to -0.64)**	**<0.001**		0.480[b]
Health-related quality of life								
Physical component summary (PCS) scores (SF-36)	**-1.20 (-1.49 to -0.90)**	**<0.001**	**-1.28 (-1.57 to-0.99)**	**<0.001**	**-1.27 (-1.58 to -0.95)**	**<0.001**	**-1.14 (-1.46 to -0.83)**	**<0.001**
Mental component summary (MCS) scores (SF-36)	**-0.46 (-0.79 to -0.14)**	**0.005**	**-0.40 (-0.73to -0.07)**	**0.017**	**-0.34 (-0.67 to -0.02)**	**0.038**		0.674[b]
Breast-related psychosocial wellbeing (BREAST-Q)	**-0.86 (-1.17 to -0.55)**	**<0.001**	**-0.81 (-1.12 to-0.49)**	**<0.001**	**-0.71 (-1.05 to -0.38)**	**<0.001**		0.414[b]
Satisfaction								
Body satisfaction (NRS)[a]	**-0.63 (-0.95 to -0.31)**	**<0.001**	**-0.61 (-0.93 to-0.29)**	**<0.001**	**-0.49 (-0.87 to -0.11)**	**0.011**		0.651[b]
Breast satisfaction (BREAST-Q)	**-0.94 (-1.25 to -0.63)**	**<0.001**	**-0.91 (-1.21 to-0.60)**	**<0.001**	**-0.85 (-1.20 to -0.51)**	**<0.001**	**-0.59 (-0.92 to -0.26)**	**<0.001**

[a] One missing value; [b] variable removed in final model (p>0.05); Bolded figures – p<0.05. **Abbreviations:** UBP - Upper back pain; NRS - Numerical rating scale; BSS - Breast size score; HAP AAS - Human Activity Profile adjusted activity score; SF-36 – Medical Outcomes Study Short-Form 36 Health Survey; PCS - Physical component summary; MCS - Mental component summary; CI - Confidence interval; yrs – Years; cm – Centimeter; kg – Kilograms; kg/m² – Kilograms per centimeter-squared.

7.6 Discussion

In this chapter, aspects of health and psychological wellbeing measured as self-report characteristics of mature-aged women that could plausibly be associated with UBP and its severity were explored. A significant finding is that SF-36 PCS scores, as a measure of HRQoL, and breast satisfaction, independent of breast size, significantly explain variability in the presence and severity of UBP. The null hypothesis of the chapter was therefore partially rejected.

Appreciating that physical, psychosocial, behavioural and lifestyle factors may both influence, and be influenced by, pain is an emergent theme in the pathogenesis of many conditions. Despite a systematic review by Briggs et al[2] stating that minimal attention had been paid to such factors in previous research on UBP, little has changed over the intervening years. Whilst the findings of this chapter confirm that larger breast size, as an isolated characteristic, is associated with an increased likelihood of UBP, the findings also highlight that when controlling for this, other factors are related to UBP and its severity. Some of the characteristics investigated here, which were described as aspects of health and psychological wellbeing with relevant links to breast size in Chapter 6, are illustrated to have independent relationships with the presence and severity of UBP. The results of this chapter therefore indicate the possible multidimensional nature of UBP and the complexity of its relationship with breast size.

Health-related quality of life, which incorporates aspects of physical and mental wellbeing, is commonly used as a hallmark of the burden of disease and pain conditions. For instance, SF-36 PCS and MCS scores have previously been shown to correlate negatively with the severity of low back pain in adults aged 18-92 years, where older females were also identified to be more likely to experience low back pain[135]. The results of this chapter show that negative correlations also exist between these summary scores and UBP severity, with the relationship being stronger for SF-36 PCS scores. Between group comparisons revealed SF-36 PCS scores in the UBP group that were below referenced norms for Australian women of comparable age[176]. This was not the case for SF-36 MCS scores, which may illustrate that the typical burden of UBP is more physical in nature. Several scales on the SF-36 used to collate the PCS score including: role limitations due to physical problems, physical function, and bodily pain make direct reference to pain as a mediator of physical aspects of HRQoL, so perhaps this is not an unexpected finding. The mean difference in SF-36 PCS scores between groups was approximately 6-points, indicating a relatively subtle but clinically meaningful HRQoL burden potentially attributable to UBP[133]. The mild severities[152] of UBP (mean NRS: 4.5/10) reported by the UBP group may explain why this

burden was not greater. Our censored regression findings indicated that a larger impact on SF-36 PCS scores would be more likely in participants with more severe UBP. The SF-36 PCS scores capture limitations of physical capacity that are attributable to a broad spectrum of health disorders, not only physical complaints such as UBP. The data from this chapter suggest that it is also possible that lower SF-36 PCS scores contribute to the UBP experience by making it more likely and more severe in mature-aged women, irrespective of their breast size. Perceptions of physical aspects of HRQoL could therefore have a discrete contribution to UBP. In Chapter 6, using the same sample of women, increasing breast size was related to deficits in HRQoL. At the same time the likelihood of UBP was reported to increase by 13% for each one-size increase in BSS. From the analysis in the current chapter it can now be speculated that there are aspects of HRQoL that may not only be a burden associated with larger breasts, but that are also independently associated with the presence and severity UBP.

Breast satisfaction, as another key characteristic related to both the presence and severity of UBP, is likely to have a complex relationship with UBP that incorporates both physical and psychosocial elements. The relationship may also be reciprocal in nature, with breast satisfaction acting as an antecedent to UBP but also related as a consequence. Breasts are an important component of body satisfaction in mature-aged women[28, 34], and perceptions of body satisfaction are affected negatively by persistent pain[273]. Poor perceptions of body satisfaction can deter important health behaviours such as physical activity[35] which may also have an indirect relationship with pain[274]. Breast satisfaction is a characteristic that differs across women with different breast sizes (Chapter 6) and shows change with age[34]. It could therefore be a transient feature with variable and diverse effects on a broad spectrum of other characteristics and behaviours linked to breast size as well as with UBP itself. Since breast satisfaction has not been previously examined in relation to UBP, the results of this chapter shed new light on this as a distinct targetable characteristic with significant potential to influence, or be influenced by, UBP. Further work is needed to fully understand the underlying mechanism as to how these relationships may be possible.

Of the other characteristics examined as factors associated with UBP in this chapter, it was of note that physical activity, body satisfaction, and BMI were not statistically independent contributors to the presence or severity of UBP in multivariable models. Although the role of these characteristics has not been shown to be distinct in this particular case, it is possible that they contribute to the strength of one or both of the two prominent variables, SF-36 PCS scores and breast satisfaction. In prior research, low physical activity levels[275, 276], low body satisfaction[277], and a greater BMI[278], for example, have been reported to have established links with HRQoL. Furthermore, there could be similar explanations for why breast size has

not been found to be of significance to UBP when considered relative to other self-report characteristics in multivariable models. Although we can confidently exclude the possibility of collinearity between closely-related characteristics in each of our multivariable models, we cannot exclude the possibility of mediation, confounding or suppression effects between variables[279].

In conclusion this chapter presents two multivariable models, each containing the self-report characteristics of age, SF-36 PCS scores, and breast satisfaction that explain some of the variance in UBP and its severity that is unrelated to breast size. The clinical relevance of these findings are firstly, that UBP has a multi-dimensional nature which is clearly reflected in its relationships with these non-physical characteristics. Secondly, two of the three most important characteristics that have been shown to be associated with the presence and severity of UBP are modifiable, namely SF-36 PCS scores and breast satisfaction. Whilst the cross-sectional nature of the data presented here do not make it possible to extrapolate causation between these characteristics and UBP in mature-aged women, it still remains possible that SF-36 PCS scores and breast satisfaction could be targeted clinically to offset the likelihood of UBP or to yield small but important improvements in UBP severity. A clinician may, for example, consider extending their subjective assessment of women presenting with UBP to explore and address modifiable factors that may underlie negative perceptions of health or low breast satisfaction. Thirdly, SF-36 PCS scores and breast satisfaction may also be considered aspects of health and psychological wellbeing that are related to UBP independent of breast size. This suggests that whilst UBP may be more likely in women with larger breasts, the wider implications of having UBP and/or larger breasts needs to be interpreted carefully. Finally, given that only a small proportion of the variance in UBP has been explained by the self-report characteristics tested in this chapter, it is likely that there are others that may play a role in the presence of UBP. This is likely to be also the case for UBP severity and further work is needed to identify these.

Chapter 8 Upper back pain and associated physical characteristics

Spencer L, McKenna L, Fary R, Jacques A, Briffa K. Upper back pain in postmenopausal women and associated physical characteristics. PLoS One. 2019; DOI:10.1371/journal.pone.0220452.

Upper back pain in postmenopausal women and associated physical characteristics

Linda Spencer ⓞ *, Leanda McKenna L, Robyn Fary ⓞ, Angela Jacques ⓞ, Kathy Briffa

School of Physiotherapy and Exercise Science, Curtin University, Perth, Western Australia, Australia

* Linda.spencer@curtin.edu.au
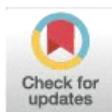
Abstract

The physical characteristics of postmenopausal women that are associated with upper back pain are not well-understood. The aim of this cross-sectional study was to identify the physical characteristics associated with presence and severity of upper back pain in healthy postmenopausal women. Self-reported upper back pain presence (within the previous month) and severity (numerical rating scale) were examined against the physical characteristics: height; weight; body mass index; breast size; breast ptosis; upper back extensor muscle endurance (isometric chest raise test); head, shoulder and upper back posture (photogrammetry); thoracic extension mobility (photogrammetry); bone mineral density (dual-energy x-ray absorptiometry (DXA)); body composition (DXA); and thoracic kyphosis, thoracic osteoarthritis and thoracic vertebral fracture (all radiography). A multivariable logistic regression model, adjusted for age, was built using physical characteristics with a significant univariate association with upper back pain. Censored Tobit regression, adjusted for age, was used to examine each physical characteristic against upper back pain severity. Postmenopausal women (n = 119) with a mean (SD) age of 61.4 (7.0) years participated in the study. After adjusting for age, the physical characteristics independently associated with upper back pain were: height (OR: 0.50, 95% CI: 0.31–0.79); and upper back extensor muscle endurance (OR: 0.46, 95%CI: 0.28–0.75). This model explained 31% of the variance in upper back pain (p<0.001). After adjusting for age, being taller and having better upper back extensor muscle endurance were associated with lower odds for upper back pain. After adjusting for age, differences in upper back pain severity were explained by upper back extensor muscle endurance (p = <0.001) and lean mass (p = 0.01). Conclusion: As a modifiable physical characteristic of postmenopausal women with upper back pain, upper back extensor muscle endurance is worth considering clinically.

Introduction

Upper back pain (UBP) describes pain in the region of the thoracic spine. It is a prevalent and disabling condition that contributes to a significantly reduced quality of life in women, particularly following menopause [1, 2]. Women are estimated to have a lifetime prevalence of UBP of between 6% [3] and 72% [4]. Risk factors related with UBP have not been clearly identified but could include an array of individual physical characteristics [4].

122

With a direct mechanical relationship to the upper back, physical characteristics such as poor posture [5]; spine mobility [6] and trunk strength [7, 8] have been associated with UBP in postmenopausal women. Similarly, decreased bone mineral density (BMD) [2, 9]; the presence of thoracic vertebral fractures [3]; and increasing thoracic kyphosis [2, 10, 11] have been related to an increased likelihood of UBP. However, these factors have not been simultaneously examined and interpretation of findings is complicated because many of these factors change with increasing age as well as being more likely following menopause.

Lack of clear definition of UBP has also hampered the evaluation of associated risk factors. Due to inadequate descriptions of the upper back region in prior epidemiological research, there is uncertainty as to which factors are related to the specific condition [4]. Whilst UBP could share a number of risk factors reported to be relevant to low back and neck pain, such as poor muscle function and non-neutral postures [12, 13], it is also likely that the condition has unique risk factors that relate more specifically to the anatomy and function of the upper torso and thoracic spine. A unique risk factor in women could be breast size, as this conceivably affects upper torso mechanics [14] and has been associated with UBP in postmenopausal women [15]. Breast size [16] and breast characteristics [17] commonly change following menopause, and whilst these characteristics have been reported to explain some of the variance in UBP in women aged 18–82 years (mean (SD) age 41 (19) years) [18], their importance and contribution to UBP alongside other potentially relevant physical characteristics, has not been previously explored.

Identifying factors that increase or decrease the risk of UBP in postmenopausal women could have significant clinical value. Specifically, knowledge of modifiable factors associated with changing the risk for UBP and its severity could be used to develop preventative and treatment strategies for the condition. Exploring these factors in postmenopausal women is particularly pertinent because they represent a growing proportion of general Australian population [19]. Since few studies have examined several physical characteristics collectively with well-defined UBP, neither the overall importance of these characteristics nor their importance relative to each other, is clear.

The aim of this study was to determine the physical characteristics of healthy postmenopausal women that were associated with the presence and severity of UBP. By exploring how women with UBP differ from those without UBP on the basis of several individual physical characteristics, we also aimed to highlight those most relevant in explaining the probability of UBP and those accounting for variability in the severity of UBP.

Materials and methods

A cross-sectional study of postmenopausal women with and without UBP was conducted. Participants were excluded if they had menstruated in the past 12 months; reported a history of thoracic spine surgery, a systemic inflammatory condition, a neurodegenerative disorder, a known pathology of the breast, lung or thoracic spine; had cancer involving the bones; previous breast surgery; or long-term and recent ongoing use of steroid or pain medication.

Women were recruited via word-of-mouth, radio, newspaper and online advertising. The study was approved by the Human Research Ethics Committee at Curtin University. (Approval number RHDS-267-15) and all participants provided written informed consent.

A survey, accessible electronically via an emailed URL link (Qualtrics, version June 2016, Provo, Utah, USA) or in hard copy by post (and returnable in postage paid envelope) captured self-report information. Information included participants' past medical history and UBP experienced within the past month.

Survey data were screened by a study supervisor (LM), who used consecutive sampling to sequentially invite at least 50 participants with UBP and 50 participants without UBP to attend

123

a university-based health clinic on one occasion, for one-hour, to complete physical measures. Participants were asked to avoid unaccustomed activity that might induce soreness in the 48 hours prior to their allocated session. An experienced musculoskeletal physiotherapist (LS), blinded to the UBP status of participants, completed the physical measures in a standardised order on each participant. Following the session, participants attended a local radiological clinic at their convenience for a thoracic spine x-ray.

Measured characteristics

Upper back pain was evaluated using the self-report information provided in completed surveys. Participants indicated the presence/absence of UBP within the previous month in response to a single question. The upper back was defined as the spine above the base of the rib cage and below the neck and a body diagram was provided for visual confirmation. Participants with UBP were asked to indicate the severity of their pain within the past month, using a numerical rating scale (NRS) of 0–10 (0 = no pain and 10 = worse pain imaginable) and the duration of their pain as acute (present for 0–3 months) or chronic (present for > 3 months).

Physical measures of participant's height (m) and weight (kg) were used to calculate their body mass index (BMI) (kg/m^2). Bone mineral density (BMD) (g/cm^2), an averaged value from the left and right femoral neck of each participant, was measured using dual-energy x-ray absorptiometry (DXA) (GE Healthcare, Little Chalfont, UK). Lean mass (kg) and fat mass (kg) were measured using whole body DXA scans [20].

Breast size was calculated from a traditional measure of bra size [21]. Under-bust and over-bust measures that determined bra size [22] were converted into a continuous breast size score (BSS) (0–18) (see S1 Appendix) using a system conceptually similar to sizing unilateral breast prostheses [23]. Breast ptosis was the measured distance (cm) between the sternal notch and nipple with participants in sitting. Distances of the left and right sides were averaged. Breast splay was the measured distance (cm) between the left and right nipples whilst participants sat with their hands on their hips. Bra fit, that examined the band, cup, underwire, straps and front brand of the bra most frequently worn by a participant over the past month was categorized as 'pass' or 'fail' using professional criteria previously described by McGhee and Steele [24].

Upper back extensor muscle endurance was tested using the isometric chest raise test [25]. This test was selected as it allowed assessment of endurance without confounding effects of poor extension mobility or a more kyphotic posture. The endurance of upper back extensor muscles was assessed in preference to the strength of the muscles in view of their primary function as postural muscles [26]. Participants were positioned in prone on a high density foam wedge cushion (Lunamumma, VIC, Australia) with the navel at the front edge of the cushion, arms unsupported and hands at the side of the head (Fig 1). The wedge cushion enabled participants with reduced extension mobility or large breasts to complete the test. Adjustable straps

Fig 1. The isometric chest raise test.

https://doi.org/10.1371/journal.pone.0220452.g001

124

were used to fix the pelvis and lower limbs (below the knee) to the bed. Instructions to "lift your chest clear of the bed and maintain this position for as long as possible" were standardised. No encouragement was given to participants during the test. The time (s) to volitional fatigue, defined as the point at which the chest touched the bed, was recorded. Any participant who could not lift the chest from the bed to initiate the test would have been recorded as having a time of zero seconds. An upper limit cut-off time of 300s was imposed to terminate the test to avoid prolonged testing time. A hold time of 300s sufficiently surpasses the 75th percentile for completion of the test by women over the age of 40-years according to normative data [8].

Upper back extension range of motion (back mobility) was determined using digital photography and methods analogous to those validated previously [27]. Photo-reflective markers were secured over the spinous processes of T1, T4, T8 and T12, identified by palpation downward from C7, before participants stood. Images (5152x3864 pixels) were taken from the left side at rest and in maximum extension. A digital camera (Nikon S3700, Nikon, Japan) on a tripod positioned 250cm away from participants, with the lens level with the mid-thoracic spine, was used. For the resting image, participants' arms were elevated anteriorly to approximately 70° with hands supported on a 122cm pole. For the extension image, participants were instructed to fully elevate their arms, reach up and back as far as possible. Photographic images were analysed using ImageJ software (National Institutes of Health, Bethesda, MD) and thoracic angles were determined for each position as previously described [27]. The difference between measured angles represented the extension range of motion (°).

Thoracic kyphosis was measured using the vertebral centroid angle on a lateral radiograph [28]. The midpoints of four thoracic vertebral bodies (T1, T2, T11, T12) were used to calculate the angle of the thoracic curve in the sagittal plane as previously described by Harrison et al. [29]. Participants stood with their arms elevated to 90°. The x-ray device was positioned at a film focus distance of 120cm with the beam centered on the mid thoracic vertebrae. Centroid angles were determined digitally (InteleViewer, Inteleard, Montreal, Canada) by a single radiologist blinded to the clinical information of each participant. X-ray images were also used to assess osteoarthritis and vertebral fractures in each participant. Clinical judgement by the radiologist was used to define the osteoarthritis of the entire thoracic spine as either nil-mild or moderate-severe. Thoracic vertebral fractures were recorded for participants showing a ≥20% loss in vertebral body height with reference to normal adjacent vertebrae [30].

Posture was also assessed using digital photography with the camera set-up as outlined above. Three angles were calculated from lateral photographs taken of participants in standing to indicate head [31], upper back [32] and shoulder posture [33] (Fig 2A–2C). Photo-reflective adhesive markers were fitted to the anatomical landmarks of interest (C7 and T7 spinous processes; tragus of the ear; and lateral mid-point of the humeral head) before participants were instructed to stand comfortably for a single left-sided photograph. Images were digitised using ImageJ software (National Institutes of Health, Bethesda, MD). Head posture (craniovertebral angle) was determined from the angle formed between a line drawn from the tragus of the ear to the seventh cervical vertebrae subtended to the horizontal (Fig 2A). Upper back posture (cervicothoracic angle) was determined from the angle between a horizontal line and a line between the seventh cervical and seventh thoracic vertebrae. (Fig 2B). Shoulder posture (shoulder protraction angle) was determined from the angle formed between a horizontal line and a line between the mid-point of the shoulder and C7 (Fig 2C).

Statistical analysis

A priori sample size calculation determined that a sample of at least 100 would be sufficient to detect change in odds for UBP of 0.9 or larger with a power of 80% and a confidence level of

125
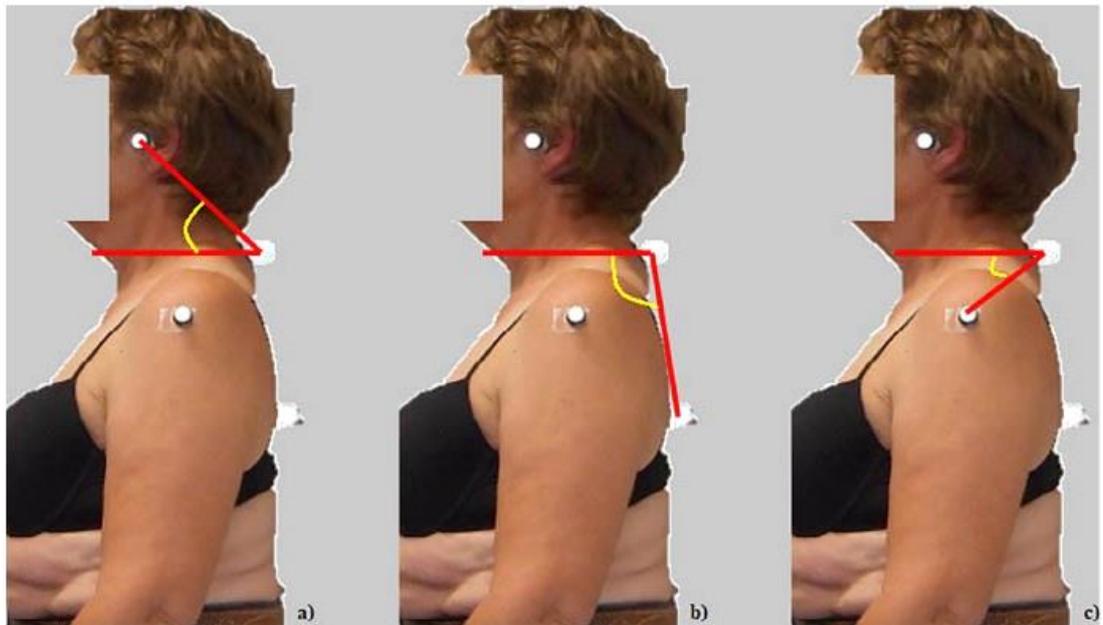
Fig 2. Posture angles—*a*: Head posture (craniocervical angle); *b*: upper back posture (cervicothoracic angle); *c*: shoulder posture (shoulder protraction angle).

95% [34]. Data were analyzed using SPSS version 24 (IBM; Chicago, IL) and STATA version 15.1 (StatCorp LP, College station, TX). Descriptive statistics were calculated for self-report and physical characteristics.

Between-group differences

The differences between groups were examined using independent-samples t-tests or Chi-square test as appropriate.

UBP risk

Each physical characteristic was then evaluated separately in a logistic regression model adjusted for age. Odds ratios were standardised by calculating them for a one standard deviation (SD) change in each variable of interest. Those variables significantly associated with UBP after adjustment for age, were entered into a multivariable model. Age was manually entered in step one and physical characteristic variables were entered forwards stepwise into the model in step 2 with probability of removal at p<0.05. The total explained variance in UBP (Yes/No) explained by the model (Nagelkerke R-squared, R^2) and physical characteristics that were statistically significant were identified. The model was confirmed using the backward stepwise method. The assumptions and standardised residual values of each model were checked and sensitivity analysis was performed where outliers (standardised residuals >2.5) were identified to be certain and confident in the model output.

126

UBP severity

Censored regression (Tobit model) analysis was used to assess univariate linear relationships between each continuous physical characteristic and UBP severity (UBP NRS). Those characteristics that were significantly associated with UBP severity after adjustment for age were entered into a multivariable model. A hierarchical Tobit multivariable regression model adjusted for age in step one was built using physical characteristics entered as z-scores. Those characteristics with a statistically significant contribution (p<0.05) to the final model were identified.

Results

A total of 119 postmenopausal women with mean (SD) age 61.4 (7.0) years; height 161.4 (6.2) cm; weight 75.2 (15.2) kg; and BMI 28.9 (5.5) kg/m^2 participated in this study. Sixty-one participants (51%) had UBP. Of these, 57 (93%) reported chronic UBP (>3 month duration). The severity of UBP reported by women with UBP ranged from 1 to 10 on the NRS with a mean (SD) of 4.56 (2.11).

Between group differences

Participants with UBP were younger, had larger breasts, greater ptosis and less upper back extensor muscle endurance (Table 1).

UBP risk

In univariate models adjusted for age, a higher BMI, larger breasts and greater ptosis were physical characteristics associated with a significant *increase* in odds for UBP (Table 1). Conversely, greater height, better upper back extensor muscle endurance, and the absence of a thoracic vertebral fracture were associated with a significant *decrease* in odds for UBP (Table 1). In the multivariable model, after adjusting for age, each SD (72.6s) increase in upper back extensor muscle endurance was significantly associated (p = 0.002) with 54% decrease in the odds of UBP and each SD (6.2cm) increase in height was significantly associated (p = 0.003) with a 50% decrease in the odds of UBP (Table 1). The age adjusted multivariable logistic regression model significantly X^2 (3) = 30.94, p<0.001, explained 31% (R^2) of the variance in UBP. The sensitivity analysis indicated that there was no change to this model by excluding two standardised residuals with a value of >2.5.

UBP severity

After adjustment for age there were six physical characteristics significantly associated with UBP severity (Table 2). Being taller, leaner and having smaller breasts, less ptosis, greater upper back extensor muscle endurance and better back mobility were significantly associated with lower severities of UBP. The multivariable model, adjusted for age and containing these physical characteristic variables identified lean mass and upper back extensor muscle endurance as the physical characteristics that independently explained differences in UBP severity. With a one standard deviation increase in age (7.0-years), lean mass (5.7kg) or upper back extensor muscle endurance (72.6), there was a significant reduction in UBP NRS score by 0.95, 0.73 and 0.91-points respectively.

Discussion

The purpose of this research was to better understand UBP in postmenopausal women by identifying associated factors. Using an exploratory approach that, for the first time, examined

127

Table 1. Logistic regression analysis. Physical characteristics and the association with UBP (yes/no).

Physical Characteristic		Descriptive Data				Multivariable Analysis			
		Whole sample (n = 119)	Nil UBP group (n = 58)	UBP group (n = 61)	Between group comparisons	Step 1: Adjustment for age		Final Model[d] Step 1: age Step 2: predictor variables (n = 119)	
		Mean (SD)	Mean (SD)	Mean (SD)	Mean Difference (95% CI)	Odds ratio (95%CI)	p-value	Odds ratio (95%CI)	p-value
Age (yrs)		61.4 (7.0)	63.8 (6.6)	59.1 (6.6)	-4.7 (-7.1 to 2.3)	0.90 (0.85–0.96)	<0.001	0.35 (0.21–0.58)	<0.001
Height (cm)		161.4 (6.2)	162.4 (5.7)	160.5 (6.5)	-1.9 (-4.1 to 0.32)	0.57 (0.37–0.87)[d]	0.010	0.50 (0.31–0.79)	0.003
Weight (kg)		75.2 (15.2)	73.9 (15.0)	76.1 (15.5)	2.6 (-2.9 to 8.2)	1.22 (0.83–1.79)	0.320		
BMI (kg/m²)		28.9 (5.5)	28.0 (5.3)	29.7 (5.6)	1.7 (-0.3 to 3.7)	1.55 (1.02–2.35)	0.039		0.289[e]
BMD (g/cm²)		0.9 (0.1)	0.9 (0.1)[a]	0.9 (0.1)[a]	0.2 (-0.02 to 0.1)	1.06 (0.72–1.58)	0.760		
Lean mass (kg)		40.6 (5.7)	56.2 (6.8)	54.3 (6.1)[a]	-0.3 (-2.4 to 1.8)	0.90 (0.61–1.33)	0.573		
Fat mass (kg)		31.7 (10.3)	42.0 (7.1)	44.0 (6.5)[a]	2.0 (-1.7 to 5.8)	1.31 (0.88–1.95)	0.168		
Breast size (BSS)		7.0 (3.2)	6.4 (2.8)	7.6 (3.4)	1.2 (0.9 to 2.3)	1.54 (1.01–2.34)	0.043		0.113[e]
Ptosis (cm)		25.6 (4.0)	24.8 (3.5)	26.4 (4.2)	1.6 (0.23 to 0.2)	1.67 (1.08–2.60)[d]	0.023		0.078[e]
Breast splay (cm)		24.3 (3.9)	23.7 (3.6)	24.8 (4.1)	1.1 (-0.3 to 2.4)	1.35 (0.91–2.01)	0.143		
Bra Fit	Pass	-	24 (41.4)[c]	19 (31.1)[c]	-	0.65 (0.29–1.43)	0.283		
	Fail		34 (58.6)[c]	42 (68.1)[c]					
Upper back extensor muscle endurance (s)		99.1 (72.6)	117.3 (85.3)	81.8 (53.2)	-35.5 (-61.5 to -9.8)	0.52 (0.33–0.82)	0.005	0.46 (0.28–0.75)	0.002
Back mobility (°)		9.3 (4.9)	9.8 (5.2)	8.8 (4.5)	-1.0 (-2.7 to 0.8)	0.85 (0.58–1.25)	0.409		
Thoracic Kyphosis centroid angle[b] (°)		42.2 (10.9)	41.8 (10.4)[a]	42.7 (11.5)[a]	0.9 (-3.1 to 4.9)	1.29 (0.86–1.94)	0.215		
Head posture (°)		38.8 (6.6)	39.1 (6.9)	38.6 (6.4)	-0.5 (-1.9 to 2.9)	0.78 (0.52–1.17)	0.223		
Upper back posture (°)		104.7 (5.6)	104.4 (5.7)	103.7 (12.4)	0.7 (-1.4 to 2.7)	1.31 (0.87–1.96)	0.197		
Shoulder posture (°)		30.3 (9.1)	29.9 (9.5)	30.7 (8.8)	0.8 (-2.5 to 4.1)	1.17 (0.80–1.73)	0.422		
Thoracic Osteoarthritis	Nil/mild	-	36 (62.1)[c]	33 (51.4)[b]	-	0.56 (0.25–1.24)	0.152		
	Moderate/severe		21 (36.2)[c]	27 (44.3)[c]					
Thoracic Fracture	Nil Fracture	-	53 (91.4)[c]	47 (77.0)[c]	-	0.12 (0.23–0.58)[d]	0.009		0.151[e]
	Fracture		4 (6.9)[c]	13 (21.3)[c]					

[a] One missing value

[b] Two missing values

[c] Categorical variables values presented as n (%)

[d] <3 outliers remained in analysis

[e] Variable removed in final model (p>0.05)

Abbreviations: UBP—Upper back pain; BMI—Body mass index; BMD—Bone mineral density; BSS—Breast size score; 95%CI: 95% confidence interval; cm–centimetres; kg–kilograms; kg/cm²–kilograms per centimeter-squared; s–seconds

128

Table 2. Censored (Tobit) regression analysis: Physical characteristics and the association with UBP severity (NRS).

| Physical characteristic | Tobit model regression (n = 119) | | | | | | | | |
| | Univariate Analysis | | | Step 1: Adjustment for age | | | Multivariable analysis Step 1: Age Step 2: Predictor variables | | |
	Tobit regression coefficient (95% CI)	Std. error	p-value	Tobit regression coefficient (95% CI)	Std. error	p-value	Tobit regression coefficient (95%CI)	Std. error	p-value
Age (yrs)	-1.04 (-1.04 to -0.62)	0.21	<0.001				-0.95 (-1.38 to -0.52)	0.22	<0.001
Height (cm)	-0.62 (-1.10 to -0.14)	0.24	0.013	-0.84 (-1.29 to -0.38)	0.23	<0.001			0.112[c]
Weight (kg)	-0.04 (-0.53 to 0.46)	0.25	0.884	-0.03 (-0.50 to 0.44)	0.24	0.892			
BMI (kg/m^2)	0.20 (-0.30 to 0.70)	0.25	0.424	0.29 (-0.18 to 0.76)	0.24	0.229			
BMD (g/cm^2)[a]	0.11 (-0.39 to 0.61)	0.25	0.660	-0.08 (-0.57 to 0.41)	0.25	0.748			
Lean mass (kg)[b]	-0.51 (-1.00 to -0.02)	0.25	0.040	-0.58 (-1.04 to -0.12)	0.23	0.015	-0.73 (-1.17 to -0.29)	0.22	0.001
Fat mass (kg)[b]	0.07 (-0.43 to 0.57)	0.25	0.780	0.13 (-0.34 to 0.60)	0.24	0.592			
Breast size (BSS)	0.50 (0.01 to 0.99)	0.25	0.044	0.47 (0.00 to 0.93)	0.23	0.049			0.945[c]
Ptosis (cm)	0.61 (0.12 to 1.09)	0.24	0.014	0.63 (0.17 to 1.08)	0.23	0.008			0.063[c]
Breast splay (cm)	0.40 (-0.09 to 0.89)	0.25	0.110	0.37 (-0.10 to 0.83)	0.24	0.123			
Upper back extensor muscle endurance (s)	-0.76 (-1.23 to -0.28)	0.24	0.002	-0.81 (-1.26 to -0.36)	0.23	0.001	-0.91 (-1.35 to -0.48)	0.22	<0.001
Back mobility (°)	-0.57 (-1.06 to -0.09)	0.25	0.021	-0.50 (-0.97 to -0.04)	0.23	0.035			0.592[c]
Thoracic Kyphosis centroid angle[b] (°)	0.24 (-0.26 to 0.74)	0.25	0.343	0.43 (-0.05 to 0.91)	0.24	0.082			
Head posture (°)	-0.05 (-0.55 to 0.44)	0.25	0.832	-0.23 (-0.71 to 0.25)	0.24	0.349			
Upper back posture (°)	0.17 (-0.33 to 0.66)	0.25	0.510	0.32 (-0.16 to 0.79)	0.24	0.190			
Shoulder posture (°)	0.17 (-0.32 to 0.67)	0.25	0.490	0.23 (-0.24 to 0.71)	0.24	0.326			

[a] Two missing values

[b] One missing value

[c] Variable removed in final model (p>0.05).

Abbreviations: BMI—Body mass index; BMD—Bone mineral density BSS—Breast size score; 95%CI—95% confidence interval; Std error—standard error; cm—centimeter; kg—kilograms; kg/m^2—kilograms per metre-squared; g/cm^2—grams per centimeter-squared; s—seconds.

several physical characteristics simultaneously in a single study, we have identified that independent of age, upper back extensor muscle endurance is the only physical characteristics that contributes to explaining variance in both the risk and severity of UBP in postmenopausal women.

Participants with UBP in this study differed overall from those without UBP on the basis of very few physical characteristics before adjusting for age. It was an unexpected finding that the odds for UBP and ratings of its severity were lower in the older participants. We are not the first to identify an inverse relationship between age and presence or severity of back pain [18, 35, 36]. The reasons for this have not been prospectively explored but could relate to a change in pain perception with age [37] or could reflect trends showing that increased musculoskeletal pain is not an inevitable consequence of ageing [38].

Risk factors for UBP have not been previously examined as a collective group in postmenopausal women. Concurrent musculoskeletal symptoms and difficulty performing activities of daily living have been previously reported as being associated with UBP in adults [4]. It is unknown whether these are, age or gender specific. In studying a broad range of physical characteristics, the current study suggests the importance that upper back extensor muscle endurance may have, over and above other physical characteristics, in the aetiology of UBP in

129

postmenopausal women. Physical characteristics such as poor posture, more severe osteoarthritis, prevalent vertebral fractures, larger thoracic kyphosis, lower back mobility and higher BMI, which anecdotally are considered common physical features of people with UBP, have been shown to be less important amongst the participants of our study. Since this is the first study to collectively assess this many different physical characteristics and the first to examine their relative importance to UBP, the results are novel and require further substantiation. It is possible, for example, that by excluding volunteers with known thoracic spine pathology that it made some physical characteristics, such as prevalent vertebral fractures and thoracic hyperkyphosis, less detectable. This may also explain the low average UBP severity scores (NRS of 4.5-points) recorded across the sample. The 'mild'[39] severity of these average scores may also have precluded us from identifying relationships between some physical characteristics and UBP severity.

Back extensor muscle endurance has not previously been investigated as a risk factor for UBP although it has been reported, as a characteristic that increases the odds for low back pain [12, 40] and chronic neck pain [13]. By showing that UBP becomes less likely with increasing levels of upper back extensor muscle endurance, our results suggest that this could be a potent targetable characteristic of postmenopausal women that may offset their risk of UBP.

Although the mechanism between upper back extensor muscle endurance and UBP remains unclear there is evidence that back muscle function can affect thoracic spinal compressive loading and that this may contribute to the development of UBP [41]. Changes to spinal loading as a result of poor back muscle endurance and the implications for spinal pain is a longstanding concept in low back pain research [42]. Since upper back extensor muscles have a primarily postural function [26] it is plausible that deficits in endurance could affect spinal loading over time which may in turn become symptomatic. Training back muscle function as a way of mitigating the compressive loading of the thoracic spine improves thoracic postures [43–47] and reduces the risk of vertebral fractures [48, 49]. The range of simple back extensor exercises, that are previously-described to have such benefits are well-tolerated by postmenopausal women with and without pathology affecting the thoracic spine [44–49]. An important direction for future research is to evaluate if the therapeutic benefits of such exercises extend to improving upper back extensor muscle endurance and beyond this to reducing the risk and severity of UBP in postmenopausal women.

It was of interest that both breast size and breast ptosis were physical characteristics associated with both the risk and severity of UBP in univariate models which helps to corroborate that UBP may have unique risk factors such as these. This is of particular relevance to older women who commonly experience an increase in breast size [16, 50, 51]. The elevated risk of UBP with increasing breast size verifies previous reports in postmenopausal [15] and younger women [14, 18]. This study has shown further that, in relation to other physical characteristics, the importance of breast size to the risk and severity of UBP may not be as substantial as previously suggested. Breast size has been descriptively linked to UBP via putative biomechanical mechanisms in studies of women with different breast sizes where other physical characteristics such as thoracic kyphosis and posture have been implicated [14, 52, 53]. The current study has been unable to confirm that thoracic kyphosis or posture (head, upper back or shoulder posture) are physical characteristics that are related to UBP risk or its severity. Whilst larger breast sizes could plausibly contribute to UBP, the role and relevance of thoracic kyphosis or posture as mediators of the relationship between breast size and UBP needs more substantiation. Further prospective investigation of the relationships between breast size and physical characteristics, alongside UBP, is needed to confirm a causative link and mechanism. Examining the potentially important role of upper back extensor muscle endurance as a factor with clear links to the risk and severity of UBP could be worthwhile.

130

Another possible unique risk factor for UBP related to breast size is breast support from a correctly fitted bra. This has been speculated as a source of UBP in women with large breasts [14]. Women with large breasts commonly wear ill-fitting bras [24, 54, 55] and are considered more likely to experience UBP as a result of this [56]. The value of a correctly fitted bra has been previously demonstrated to reduce breast pain [57] and improve comfort with physical activity amongst women with large breasts [58, 59]. However, correct bra fit has not been previously examined as a factor related to UBP. Since there was no significant association between bra fit and UBP, our findings do not support the concept that a correctly-fitted bra may "protect" against UBP in postmenopausal women [56]. Whether this is dependent on the size of a woman's breasts or the specific characteristics of her bra, requires further exploration.

In this study, upper back extensor muscle endurance, age and height were physical characteristics that collectively explained less than half (31%) of the variance in UBP risk, suggesting there are other characteristics, that have not been examined here, that may account for the remaining 69% of the variance. Furthermore, the characteristics of age, upper back extensor muscle endurance and lean body mass contributed only very small amounts to changes in UBP severity and of note, only one of these is reasonably easy to change for postmenopausal women. These outcomes suggest that further work is needed to identify factors associated with the risk and severity of UBP in postmenopausal women. This could include an examination of psychosocial characteristics, which have received little attention in the study of UBP in the past but could, nevertheless, be of importance [4].

The findings of this study should be considered in the context of its limitations. The study considered what physical characteristics may be risk factors for UBP. Causal relationships cannot be assumed, due to the cross-sectional design of our study. Upper back pain quantified using the NRS revealed relatively low levels of pain severity across participants in our sample. This may have concealed some of the relationships that we could identify between physical characteristics and UBP risk and severity. Targeting a sample with higher pain scores may overcome this limitation in the future.

In summary, this study concludes that, irrespective of age, postmenopausal women may be less likely to suffer from UBP and severe pain if they maintain good upper back extensor muscle endurance. There is some evidence that breast characteristics, including size and ptosis, are characteristics that are relevant to UBP in postmenopausal women but as risk factors these are less conspicuous.

Supporting information

S1 Appendix. Breast size score conversion chart.
(DOCX)

Acknowledgments

Author Contributions

Conceptualization: Linda Spencer.

Data curation: Linda Spencer.

Formal analysis: Linda Spencer, Angela Jacques, Kathy Briffa.

131

Investigation: Linda Spencer.

Methodology: Linda Spencer.

Project administration: Linda Spencer.

Supervision: Leanda McKenna, Robyn Fary, Kathy Briffa.

Writing – original draft: Linda Spencer.

Writing – review & editing: Linda Spencer, Leanda McKenna, Robyn Fary, Kathy Briffa.

References

1. Brown WJ, Mishra GD, Dobson A. Changes in physical symptoms during the menopause transition. International J Behav Med. 2002; 9(1):53–67.

2. Ryan PJ, Blake G, Herd R, Fogelman I. A clinical profile of back pain and disability in patients with spinal osteoporosis. Bone. 1994; 15(1):27–30. http://dx.doi.org/10.1016/8756-3282(94)90887-7. PMID: 8024847

3. Huang C, Ross PD, Wasnich RD. Vertebral fractures and other predictors of back pain among older women. J Bone Miner Res. 1996; 11(7):1026–32. https://doi.org/10.1002/jbmr.5650110721 PMID: 8797125

4. Briggs A, Bragge P, Smith AJ, Govil D, Straker LM. Prevalence and associated factors for thoracic spine pain in the adult working population: a literature review. J Occup Health. 2009; 51(3):177–92. https://doi.org/10.1539/joh.k8007 PMID: 19336970

5. Drzal-Grabiec J, Snela S, Rykala J, Podgorska J, Banas A. Changes in the body posture of women occurring with age. BMC Geriatr. 2013; 13:108. https://doi.org/10.1186/1471-2318-13-108 PMID: 24119004

6. Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. Spine J. 2004; 4(4):413–7. https://doi.org/10.1016/j.spinee.2004.01.002 PMID: 15246302

7. Granito RN, Aveiro MC, Rennó ACM, Oishi J, Driusso P. Degree of thoracic kyphosis and peak torque of trunk flexors and extensors among healthy women. Rev Bras de Ortop. 2014; 49(3):286–91. http://dx.doi.org/10.1016/j.rboe.2014.04.002.

8. McIntosh G, Wilson L, Affieck M, Hall H. Trunk and lower extremity muscle endurance: normative data for adults. J Rehabil Out Measures. 1998; 2:20–39.

9. Kado DM, Huang MH, Karlamangla AS, Cawthon P, Katzman W, Hillier TA, et al. Factors associated with kyphosis progression in older women: 15 years' experience in the study of osteoporotic fractures. J Bone Miner Res 2013; 28(1):179–87. https://doi.org/10.1002/jbmr.1728 PMID: 22865329

10. Ettinger B, Black DM, Palermo L, Nevitt MC, Melnikoff S, Cummings SR. Kyphosis in older women and its relation to back pain, disability and osteopenia: The study of osteoporotic fractures. Osteoporos Int. 1994; 4(1):55–60. PMID: 8148573

11. Ensrud KE, Black DM, Harris F, Ettinger B, Cummings SR. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. J Am Geriatr So. 1997; 45(6):682–7.

12. Smith A, Beales D, O'Sullivan P, Bear N, Straker L. Low Back Pain With Impact at 17 Years of Age Is Predicted by Early Adolescent Risk Factors From Multiple Domains: Analysis of the Western Australian Pregnancy Cohort (Raine) Study. J Orthop Sports Phys Ther. 2017; 47(10):752–62. https://doi.org/10.2519/jospt.2017.7464 PMID: 28915771

13. Shahidi B, Curran-Everett D, Maluf KS. Psychosocial, Physical, and Neurophysiological Risk Factors for Chronic Neck Pain: A Prospective Inception Cohort Study. J Pain. 2015; 16(12):1288–99. https://doi.org/10.1016/j.jpain.2015.09.002 PMID: 26400680

14. McGhee D, Coltman KA, Riddiford-Harland DL, Steele JR. Upper torso pain and musculoskeletal structure and function in women with and without large breasts: A cross sectional study. Clin Biomech. 2018; 51:99–104. https://doi.org/10.1016/j.clinbiomech.2017.12.009.

15. Spencer L, Briffa K. Breast size, thoracic kyphosis & thoracic spine pain—association & relevance of bra fitting in post-menopausal women: a correlational study. Chiropr Man Ther. 2013; 21(20):1–8.

16. den Tonkelaar I, Peeters PHM, van Noord PAH. Increase in breast size after menopause: prevalence and determinants. Maturitas. 2004; 48(1):51–7. https://doi.org/10.1016/j.maturitas.2003.10.002 PMID: 15223108

132

17. Machida Y, Nakadate M. Breast Shape Change Associated with Aging: A Study Using Prone Breast Magnetic Resonance Imaging. Plast Reconstr Surg. 2015; 3(6):e413. https://doi.org/10.1097/gox.0000000000000289 PMID: 26180714

18. Coltman CE, Steele JR, McGhee DE. Can breast characteristics predict upper torso musculoskeletal pain? Clin Biomech. 2018; 53:46–53. https://doi.org/10.1016/j.clinbiomech.2018.02.002 PMID: 29448080

19. Australian Bureau of Statistics. Population projections, Australia, 2012 (base) to 2021. Canberra: Austraian Bureau of Statistics (ABS); 2013.

20. Shepherd JA, Ng BK, Sommer MJ, Heymsfield SB. Body composition by DXA. Bone. 2017; 104:101–5. https://doi.org/10.1016/j.bone.2017.06.010 P. PMID: 28625918

21. Zheng R, Yu W, Fan J. 2—Breast measurement and sizing. In: Yu W, Fan J, Harlock SC, Ng SP, editors. Innovation and Technology of Women's Intimate Apparel: Woodhead Publishing; 2006. p. 28–58.

22. Berlei. Australian Bra Sizes: Berlei; 2018 [January 2018]. Available from: https://www.berlei.com.au/size-charts.

23. Ameona. Breast Form Fitting Guide: Ameona; 2017 [cited 2015]. Available from: http://www.amoena.com/au/about-us/breast-form-fitting-guide/.

24. McGhee D, Steele J. Optimising breast support in female patients through correct bra fit: A cross-sectional study. J Sci Med Sport. 2010; 13, Supplement 1(0):e87. http://dx.doi.org/10.1016/j.jsams.2010.10.646.

25. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. Arch Phys Med Rehabil. 1996; 77(1):75–9 PMID: 8554479

26. Mannion AF, Dumas GA, Cooper RG, Espinosa FJ, Faris MW, Stevenson JM. Muscle fibre size and type distribution in thoracic and lumbar regions of erector spinae in healthy subjects without low back pain: normal values and sex differences. J Anat. 1997; 190:505–13. https://doi.org/10.1046/j.1469-7580.1997.19040505.x PMID: 9183674

27. Edmondston SJ, Christensen MM, Keller S, Steigen LB, Barclay L. Functional Radiographic Analysis of Thoracic Spine Extension Motion in Asymptomatic Men. J Manipulative Physiol Ther. 2012; 35(3):203–8. https://doi.org/10.1016/j.jmpt.2012.01.008 PMID: 22386914

28. McAlister WH, Shackelford GD. Measurement of spinal curvatures. Radiol Clin North Am. 1975; 13(1):113–21. PMID: 1129445

29. Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B. Reliability of centroid, Cobb, and Harrison posterior tangent methods: which to choose for analysis of thoracic kyphosis. Spine. 2001; 26(11): E227–34. PMID: 11389406

30. Griffith JF. Identifying osteoporotic vertebral fracture. Quant Imaging Med Surg. 2015; 5(4):592–602. https://doi.org/10.3978/j.issn.2223-4292.2015.08.01 PMID: 26435923

31. Raine S, Twomey L. Posture of the head, shoulders and thoracic spine in comfortable erect standing. Aust J Physiother. 1994; 40(1):25–32. https://doi.org/10.1016/S0004-9514(14)60451-7 PMID: 25026488

32. Falla D, Jull G, Russell T, Vicenzino B, Hodges P. Effect of neck exercise on sitting posture in patients with chronic neck pain. Phys Ther. 2007; 87(4):408–17. https://doi.org/10.2522/ptj.20060009 PMID: 17341512

33. Raine S, Twomey LT. Head and shoulder posture variations in 160 asymptomatic women and men. Arch Phys Med Rehabil. 1997; 78(11):1215–23. https://doi.org/10.1016/S0003-9993(97)90335-X. PMID: 9365352

34. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods. 2009; 41(4):1149–60. https://doi.org/10.3758/BRM.41.4.1149 PMID: 19897823

35. Fejer R, Leboeuf-Yde C. Does back and neck pain become more common as you get older? A systematic literature review. Chiropr Man Ther. 2012; 20(1):24. https://doi.org/10.1186/2045-709x-20-24 PMID: 22883425

36. Dionne CE, Dunn KM, Croft PR. Does back pain prevalence really decrease with increasing age? A systematic review. Age Ageing. 2006; 35(3):229–34. https://doi.org/10.1093/ageing/afj055 PMID: 16547119

37. Gibson SJ, Helme RD. Age-related differences in pain perception and report. Clin Geriatr Med. 2001; 17(3):433–56, v-vi. PMID: 11459714

38. Parsons S, Breen A, Foster NE, Letley L, Pincus T, Vogel S, et al. Prevalence and comparative troublesomeness by age of musculoskeletal pain in different body locations. Fam Pract. 2007; 24(4):308–16. https://doi.org/10.1093/fampra/cmm027 PMID: 17602173

133

39. Boonstra AM, Stewart RE, Köke AJA, Oosterwijk RFA, Swaan JL, Schreurs KMG, et al. Cut-off points for mild, moderate, and severe pain on the numeric rating scale for pain in patients with chronic musculoskeletal pain: variability and influence of sex and catastrophizing. Front Psychol. 2016; 7:1466–. https://doi.org/10.3389/fpsyg.2016.01466 PMID: 27746750

40. O'Sullivan PB, Mitchell T, Bulich P, Waller R, Holte J. The relationship beween posture and back muscle endurance in industrial workers with flexion-related low back pain. Man Ther. 2006; 11(4):264–71. https://doi.org/10.1016/j.math.2005.04.004 PMID: 15953751

41. Briggs A, van Dieën JH, Wrigley TV, Greig AM, Phillips B, Lo SK, et al. Thoracic Kyphosis Affects Spinal Loads and Trunk Muscle Force. Phys Ther. 2007; 87(5):595–607. https://doi.org/10.2522/ptj.20060119 PMID: 17472956

42. O'Sullivan P. Diagnosis and classification of chronic low back pain disorders: maladaptive movement and motor control impairments as underlying mechanism. Man Ther. 2005; 10(4):242–55. Epub 2005/09/13. https://doi.org/10.1016/j.math.2005.07.001 PMID: 16154380.

43. Greendale GA, Huang MH, Karlamangla AS, Seeger L, Crawford S. Yoga decreases kyphosis in senior women and men with adult-onset hyperkyphosis: results of a randomized controlled trial. J Am Geriatr Soc. 2009; 57(9):1569–79. https://doi.org/10.1111/j.1532-5415.2009.02391.x PMID: 19682114

44. Itoi E, Sinaki M. Effect of back-strengthening exercise on posture in healthy women 49 to 65 years of age. Mayo Clin Proc. 1994; 69(11):1054–9. https://doi.org/10.1016/s0025-6196(12)61372-x PMID: 7967758

45. Jang HJ, Kim MJ, Kim SY. Effect of thorax correction exercises on flexed posture and chest function in older women with age-related hyperkyphosis. J Phys Ther Sci. 2015; 27(4):1161–4. https://doi.org/10.1589/jpts.27.1161 PMID: 25995579

46. Jang HJ, Hughes LC, Oh DW, Kim SY. Effects of corrective exercise for thoracic hyperkyphosis on posture, balance, and well-being in older women: A double-blind, group-matched design. J Geriatr Phys Ther (2001). https://doi.org/10.1519/jpt.0000000000000146 PMID: 28914720

47. Katzman WB, Sellmeyer DE, Stewart AL, Wanek L, Hamel KA. Changes in flexed posture, musculoskeletal impairments, and physical performance after group exercise in community-dwelling older women. Arch Phys Med Rehabil. 2007; 88(2):192–9. https://doi.org/10.1016/j.apmr.2006.10.033 PMID: 17270517

48. Sinaki M, Itoi E, Wahner HW, Wollan P, Gelzcer R, Mullan BP, et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone. 2002; 30(6):836–41. PMID: 12052450

49. Sinaki M, Wollan PC, Scott RW, Gelczer RK. Can strong back extensors prevent vertebral fractures in women with osteoporosis? Mayo Clin Proc. 1996; 71(10):951–6. https://doi.org/10.1016/S0025-6196(11)63768-3 PMID: 8820769

50. Risius D, Thelwell R, Wagstaff CRD, Scurr J. The influence of ageing on bra preferences and self-perception of breasts among mature women. Eur J Ageing. 2014; 11(3):233–40. https://doi.org/10.1007/s10433-014-0310-3 PMID: 28804329

51. Hammann-Kloss JS, Bick U, Fallenberg E, Engelken F. Volumetric quantification of the effect of aging and hormone replacement therapy on breast composition from digital mammograms. Eur J Radiol. 2014; 83(7):1092–7. https://doi.org/10.1016/j.ejrad.2014.03.028 PMID: 24788077

52. Findikcioglu K, Findikcioglu F, Ozmen S, Guclu T. The impact of breast size on the vertebral column: A radiologic study. Aesthetic Plast Surg. 2007; 31:23–7. https://doi.org/10.1007/s00266-006-0178-5 PMID: 17205252

53. Schinkel-Ivy A, Drake JD. Breast size impacts spine motion and postural muscle activation. Journal of back and musculoskeletal rehabilitation. 2016; 29(4):741–8. https://doi.org/10.3233/BMR-160680 PMID: 26966826

54. Wood K, Cameron M, Fitzgerald K. Breast size, bra fit and thoracic spine pain in young women: A correlational study. Chiropr Osteopat. 2008; 16(1):1340–7.

55. Coltman CE, Steele JR, McGhee DE. Which bra components contribute to incorrect bra fit in women across a range of breast sizes? Cloth Text Res J. 2017; 36(2):78–90. https://doi.org/10.1177/0887302X17743814

56. Greenbaum AR, Heslop T, Morris J, Dunn KW. An investigation of the suitability of bra fit in women referred for reduction mammaplasty. Brit J Plastic Surg. 2003; 56(3):230–6. http://dx.doi.org/10.1016/S0007-1226(03)00122-X.

57. Smith RL, Pruthi S, Fitzpatrick LA. Evaluation and management of breast pain. Mayo Clin Proc. 2004; 79(3):353–72. 10.4065/79.3.353. https://doi.org/10.4065/79.3.353 PMID: 15008609

58. Coltman C, McGhee D, Steele J. Bra strap orientations and designs to minimise bra strap discomfort and pressure during sport and exercise in women with large breasts. Sports Med. 2015; 2(1):5.

134

59. McGhee D, Steele JR, Zealey WJ, Takacs GJ. Bra–breast forces generated in women with large breasts while standing and during treadmill running: Implications for sports bra design. Appl Ergon. 2013; 44(1):112–8. https://doi.org/10.1016/j.apergo.2012.05.006 PMID: 22742876

135

S1 Appendix Breast Size Score (BSS) Conversion Chart[a]

	Cup Size	Band size (under-bust circumference, cm)									
		8 (63-67)	10 (68-72)	12 (73-77)	14 (78-82)	16 (83-87)	18 (88-92)	20 (93-97)	22 (98-102)	24 (103-107)	26 (108-112)
Breast size score (over-bust circumference, cm)	AA	0 (75-77)	1 (80-82)	2 (85-87)	3 (90-92)	4 (95-97)	5 (100-102)	6 (105-107)	7 (110-112)	8 (115-117)	9 (120-122)
	A	1 (77-79)	2 (82-84)	3 (87-89)	4 (92-94)	5 (97-99)	6 (102-104)	7 (107-109)	8 (112-114)	9 (117-119)	10 (122-124)
	B	2 (79-81)	3 (84-86)	4 (89-91)	5 (94-96)	6 (99-101)	7 (104-106)	8 (109-111)	9 (114-116)	10 (119-121)	11 (124-126)
	C	3 (81-83)	4 (86-88)	5 (91-93)	6 (96-98)	7 (101-103)	8 (106-108)	9 (111-113)	10 (116-118)	11 (121-123)	12 (126-128)
	D	4 (83-85)	5 (88-90)	6 (93-95)	7 (98-100)	8 (103-105)	9 (108-110)	10 (113-115)	11 (118-120)	12 (123-125)	13 (128-130)
	DD	5 (85-87)	6 (90-92)	7 (95-97)	8 (100-102)	9 (105-107)	10 (110-112)	11 (115-117)	12 (120-122)	13 (125-127)	14 (130-132)
	E	6 87-89)	7 (92-94)	8 (97-99)	9 (102-104)	10 (107-109)	11 (112-114)	12 (117-119)	13 (122-124)	14 (127-129)	15 (132-134)
	F	7 (89-91)	8 (94-96)	9 (99-101)	10 (104-106)	11 (109-111)	12 (114-116)	13 (119-121)	14 (124-126)	15 (129-131)	16 (134-136)
	G	8 (91-93)	9 (96-98)	10 (101-103)	11 (106-108)	12 (111-113)	13 (116-118)	14 (121-123)	15 (126-128)	16 (131-133)	17 (136-138)
	H	9 (93-95)	10 (98-100)	11 (103-105)	12 (108-110)	13 (113-115)	14 (118-120)	15 (123-125)	16 (128-130)	17 (133-135)	18 (138-140)

[a] To determine a breast size score first identify the correct bra size (band and cup size). Establish the correct band size by measuring around the body, directly below the bust (under-bust circumference) and the correct cup size by measuring across the fullest part of the breasts whilst wearing a bra (over-bust circumference) [22]. Use the top row of the table to select the band size, this increases from left to right. Then use the first column of the table to select the cup size, this increases from top to bottom. Track down and across to find the table cell where these two selections intersect. Breast size score is shown in bolded text.

Attribution Statement							
Co-authored publication	**Conception, design and methodology**	**Implementation of the methodology and acquisition of data**	**Data analysis**	**Interpretation and discussion**	**Writing of original draft**	**Review and editing**	**Final approval**
Chapter 8. Upper back pain in postmenopausal women and associated physical characteristics							
Thesis Candidate: Linda Spencer	✓	✓	✓	✓	✓	✓	✓
Thesis Candidate Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 1: Dr Leanda McKenna	✓			✓		✓	✓
Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 2: Dr Robyn Fary	✓			✓		✓	✓
Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 3: Ms Angela Jacques	✓		✓	✓		✓	✓
Co Author 3 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 4: Dr Kathy Briffa	✓		✓	✓		✓	✓
Co Author 4 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Chapter 9   Breast size and associated physical characteristics

9.1   Abstract

Objectives: The physical basis for symptoms such as upper back pain (UBP) in women with large breasts has not been determined. There are, however, physical characteristics that are assumed to be relevant to explaining the relationship between breast size and UBP. This chapter examines whether some physical characteristics are associated with breast size to begin exploring plausible mechanisms for UBP that may explain why women with large breasts commonly experience this condition.

Methods: This chapter re-examines the dataset of 119 postmenopausal women (postmenopausal subset) who underwent objective assessment of a range of physical characteristics. Breast size (BSS) was examined against: upper back extensor muscle endurance (isometric chest raise test), upper back mobility (photogrammetry), thoracic kyphosis (radiography) and posture (photogrammetry). In addition, breast size was also examined in relation to participant's anthropometric data (height, lean mass, fat mass, breast ptosis and breast splay). Correlations between breast size and each physical characteristic were determined and linear regression models adjusted for age established if breast size explained a significant proportion of the variance in each physical characteristic.

Results: Participants with larger breasts had significantly greater body fat, breast ptosis and breast splay. Increasing breast size was related to less upper back extensor muscle endurance (r=-0.26), a more forward head posture (r=-0.23), a more rounded upper back posture (r=0.25) and a more forward shoulder posture (r=-0.24). Breast size explained a significant but small proportion of the variance in upper back extensor muscle endurance (7%), head posture (9%), upper back posture (9%), and shoulder posture (6%).

Conclusion: Upper back extensor muscle endurance and posture are physical characteristics weakly related to breast size. Other factors are likely to be more important than breast size in explaining differences in these physical characteristics. It remains uncertain if having larger breasts affects other physical characteristics that could be relevant to explaining UBP.

9.2 Introduction

It is clear that some women experience a burden as a consequence of their large breast size. Upper back pain is a common physical complaint related to this burden[25, 26, 40, 41, 69]. In prior chapters we have examined how large breasts are associated with aspects of health and psychological wellbeing but, to understand the full picture of the burden of large breasts, we need to also understand the relationships between breast size and physical characteristics. Self-reported health and psychological wellbeing characteristics, for example, do not entirely explain symptoms such as UBP. A physical basis for UBP in women with large breasts has reasonable theoretical grounding[27] but largely remains unconfirmed.

Physical characteristics that vary between women with different breast sizes could provide insight into the mechanism by which large breasts contribute to UBP. To date, there has been limited examination of these differences in women with a broad range of breast sizes who are not undergoing reduction mammoplasty.

Increased thoracic kyphosis[27, 40, 50, 51] and posture problems[48, 67] are descriptively linked to UBP that have been observed in women with large breasts seeking reduction mammoplasty. Thoracic kyphosis and posture are also physical characteristics shown to vary between women of different breast size who are not seeking reduction mammoplasty[23, 53, 55]. An accentuated thoracic kyphosis and postural adaptations to large breasts, that increase the load on musculoskeletal tissues in the upper back, provide a theoretical basis for UBP[27]. Although this is plausible, there could also be other physical characteristics, yet to be identified, that account for UBP experienced by women with large breasts.

In this chapter the physical characteristics of the postmenopausal subset are re-examined, this time exploring those physical characteristics associated with breast size. The purpose of this supporting chapter was to identify characteristics related to breast size that show any consistency with the theoretical physical explanation for UBP in women with large breasts. Of particular interest was whether the findings of prior research could be corroborated by showing that thoracic kyphosis and posture are characteristics related to breast size. Further to this, in consideration of the findings of our UBP study[256a] (Chapter 8), another aim of the current chapter was to establish trends between those physical characteristics related to breast size and those related to UBP.

9.3 Methods

The datasets of 119 women included in the postmenopausal subset were analysed. Full details on the recruitment (section 2.2.2) of this sample and the methods used to assess their physical characteristics (section 2.7) are described elsewhere.

For the purposes of this chapter, data collected on the physical characteristics listed in Table 9.1 were analysed. These physical characteristics were considered to be relevant to explaining the relationship between breast size and UBP and were selected purposefully from those assessed in this doctoral research project.

Participants attended a university-based health centre on one occasion to undergo a battery of physical measures as described in Chapter 2, section 2.7. Participants also attended a local radiological clinic for a lateral thoracic X-ray as described in section 2.7.8. For the purposes of this chapter, breast size was explored as an independent variable. Breast size was quantified as a BSS (Appendix 4b). This was determined by objectively using under-bust and over-bust circumferences as described in detail in Chapter 2, section 2.7.4 and Chapter 4.

Table 9.1 Physical characteristics examined

Variable (physical characteristic)	Objective method	Methods reference link
Anthropometry		
Height (cm)	Stadiometer	Section 2.7.1
Body composition	Dual energy X-ray absorptiometry	Section 2.7.3
Lean mass (kg)		
Fat mass (kg)		
Breast characteristics		Section 2.7.4
Breast size (BSS)		
Breast ptosis (cm)	Tape measure	
Breast splay (cm)		
Upper back extensor muscle endurance (s)	Isometric chest raise test	Section 2.7.6
Upper back mobility		Section 2.7.7
Thoracic extension range of movement (°)	Photogrammetry	
Thoracic kyphosis		
Radiographic thoracic kyphosis (°)[a]	Plain X-ray	Section 2.7.8
Posture		Section 2.7.10
Head posture (craniovertebral angle) (°)		
Upper back posture (cervicothoracic angle) (°)	Photogrammetry	
Shoulder posture (shoulder protraction angle) (°)		

Abbreviations: cm – centimeter; kg – Kilograms; BSS - Breast size score; s – Seconds.

9.4 Statistical analysis

Data were analysed using SPSS version 24 (IBM, Chicago, IL). Pearson product-moment correlation coefficients (r) were used to assess the direction and strength of linear associations between breast size and each physical characteristic which were interpreted as: weak ($r<0.3$), moderate ($r=0.3-0.5$) or strong ($r>0.5$)[263].

Linear regression established if breast size accounted for significant variability in each physical characteristic using univariate models adjusted for age. Assumptions of each model were checked and sensitivity analyses were completed where outliers were identified. Outliers (z-residuals >2.5) remained in the analysis if removing them made no difference to the outcome of the model. The proportion of variance explained by breast size was estimated (R-squared, R^2) and statistical significance was set at $p<0.05$.

9.5 Results

A total of 119 datasets were analysed. Two participants failed to undergo a thoracic X-ray. One participant had an incomplete body composition scan due to her body size exceeding that of the scanner bed. The mean (SD) age, height, and breast size respectively were: 61.4 (7.0) years, 161.4 (6.2) cm, and 7.0 (3.2) sizes.

Participants with larger breasts had significantly greater lean and fat mass although the correlation was stronger between breast size and fat mass ($r=0.8$) (Table 9.2). Breast size was strongly correlated with breast ptosis and breast splay, indicating participants with larger breasts had greater breast ptosis and breast splay (Table 9.2).

Participants with larger breasts had significantly less upper back extensor muscle endurance but breast size only accounted for 7% of the variability in this physical characteristic (Table 9.2). Breast size explained a small amount of variance in head, upper back and shoulder posture where larger breast size was associated with a more forward head posture (smaller craniovertebral angle), a more rounded upper back posture (greater cervicothoracic angle), and more protracted shoulder posture (smaller shoulder protraction angles) (Table 9.2). Breast size was unrelated to upper back mobility and thoracic kyphosis (Table 9.2).

Table 9.2 Physical characteristics associated with breast size. Linear regression output

Physical Characteristic	n	Breast size (BSS) Correlation (*r*)	Linear Regression analysis adjusted for age		
			Variance explained (R^2)	Unstandardised beta coefficient (95%CI)	p-value
Height (cm)	119	0.08	0.05	0.14 (-0.21 to 0.49)	0.423
Lean mass (kg)[a]	**118**	**0.51**	**0.27**	**0.98 (0.67 to 1.28)**	**<0.001**
Fat mass (kg)[a]	**118**	**0.79**	**0.64**	**2.71 (2.33 to 3.09)[d]**	**<0.001**
Breast ptosis (cm)	**119**	**0.78**	**0.62**	**0.98 (0.84 to 1.12)[c]**	**<0.001**
Breast splay (cm)	**119**	**0.74**	**0.54**	**0.90 (0.75 to 1.05)[c]**	**<0.001**
Upper back extensor muscle endurance (s)	**119**	**-0.26**	**0.07**	**-5.91 (-9.98 to -1.85)**	**0.005**
Upper back mobility (°)	119	-0.16	0.03	-0.25 (-0.52 to 0.03)	0.083
Thoracic kyphosis (°)[b]	117	0.06	0.05	0.23 (-0.40 to 0.85)	0.472
Head posture (°)	**119**	**-0.23**	**0.09**	**-0.50 (-0.86 to -0.13)**	**0.008**
Upper back posture (°)	**119**	**0.25**	**0.09**	**0.45 (0.14 to 0.76)[c]**	**0.005**
Shoulder posture (°)	**119**	**-0.24**	**0.06**	**-0.67 (-1.19 to -0.16)[c]**	**0.010**

[a] one missing value; [b] two missing values; [c] one outlier (z-residual >2.5) remained in analysis; [d] two outliers (z-residual>2.5) remained in the analysis; Bolded figures – p<0.05. **Abbreviations:** BSS – Breast size score; *r* – Pearson product-moment correlation coefficient; CI – Confidence interval; cm – Centimeter; kg – Kilograms; s – Seconds.

9.6 Discussion

While it is generally accepted that large breast sizes in women contribute to UBP, the physical basis for this is poorly understood. In the absence of prospective evidence, the mechanism explaining the relationship between increasing breast size and UBP remains uncertain. Using trends in cross-sectional data, the findings of this chapter have, however, identified some of the physical characteristics coexisting with larger breasts. In doing so, it provides some insight into the plausibility of the mechanisms that have been theoretically proposed[27]. The findings of this chapter, consistent with those theories, are that increasing breast size is associated with a more forward head, a more rounded upper back and a protracted shoulder posture. In addition, the findings reveal a new negative relationship between breast size and upper back extensor muscle endurance. An important finding of this chapter was that all of the relationships that have been identified are weak and while differences in these physical characteristics are significantly explained by breast size, they are only weakly explained. In addition, an unexpected finding of this chapter was that breast size showed no appreciable relationship with thoracic kyphosis.

The postural adaptations to large breasts that have been previously described include: a more forward head posture, a more rounded upper back, and more protracted shoulders[27]. Despite

it being generally accepted that large breasts contribute to the development of these aberrant postural features, there has been limited objective evidence to confirm this. Studies assessing posture related to breast size have investigated different posture angles using a range of different methods (refer to section 1.2.4). There have been no two studies that report on the same postural characteristic measured in the same way. There has also been inconsistent evidence that breast size is related to posture, and this evidence has been generated from studies using small samples of women showing very little diversity in breast sizes.

In women not seeking reduction mammoplasty, two studies have examined posture in relation to breast size[55, 56]. Schinkel and Drake[55], using a 3D system to assess posture in a small sample (n=15) of young women (mean age 23 years) with breast sizes ranging from bra cup size B to D, demonstrated that head angles were significantly more extended in women with larger breasts and that breast size accounted for 44% of the variance in head (cervical) angles. In our comparatively larger sample of women with a much broader range of breast sizes, we also found head posture angles were more forward/extended with increasing breast size. Unlike the smaller study by Schinkel and Drake[55] however, the strength of the relationship between breast size and head posture angles recorded in our work was weak, with our coefficients of determination showing that breast size accounted for only 9% of the variance in head posture angles. Of note, the mean head posture angle of our participants was well below age-referenced norms[244, 280] reported using the same methods. This indicates that participants in our postmenopausal subset overall, more commonly had a forward head posture. This may have made it more difficult to ascertain a strong relationship between breast size and head posture given the direction of the relationship.

The relationship identified between breast size and head posture in our postmenopausal subset contrast the findings of another small (n=22) study of young (aged 18-35 years) women which used photographic methods to assess head and scapular position[56]. It was noted by the authors of this small study that the characteristics of their sample (age and BMI) may have contributed to the unexpected finding that breast size was not significantly related to head posture or scapular position. The study did not examine the linear relationship between breast size and head posture but rather the postural differences between two breast size groups (small versus large breasts). These methodological factors may also explain why findings did not reach statistical significance. The authors suggested that postural adaptations to large breasts would be more likely to be measurable in women of an older age than were included in their sample and our findings verify this to some extent.

Upper back and shoulder posture are variables that have not been extensively examined in relation to breast size despite there being a theoretical rationale for a relationship[27]. In our

postmenopausal subset, breast size was linearly related to upper back posture in a weak positive relationship, indicating that larger breasts were associated with a more rounded upper back posture. It was of interest that breast size showed a relationship with upper back posture but not with thoracic kyphosis in our analysis, indicating a potential difference between thoracic posture and thoracic kyphosis. This is relevant in a field of research which often uses these terms interchangeably. The upper back posture measure that we employed more specifically assessed the upper thoracic spine whereas the thoracic kyphosis measure assessed the contour of the thoracic spine more fully. This may be another reason why upper back posture and thoracic kyphosis results did not align.

The relationship identified between breast size and shoulder posture in our work is a novel finding that supports previous descriptive accounts that larger breasts are associated with a more protracted shoulder posture[27]. Compared to age-referenced norms our participants had shoulder postures that were more protracted than average[244]. This was perhaps not unexpected when these participants also had a more forward head posture than average. The relationship between head and shoulder posture has been previously cited[281] and our results support a close relationship between these posture variables.

Whilst the findings of this chapter identify relationships between breast size and posture in expected directions, these relationships are weak. The cross-sectional nature of the data presented here do not confirm that a more forward head, a more rounded upper back or more protracted shoulders represent postural adaptations to large breasts, but it is noteworthy that the negative relationships between breast size and posture variables, whilst being weak, were independent of age. Based on the coefficients of determination, which were 0.09 or lower for head, upper back and shoulder posture, it is likely that other factors are more important than breast size in explaining differences in posture amongst the participants of our sample.

Upper back extensor muscle endurance has not been previously examined in relation to breast size although it has been speculated that upper back extensor muscles have a biomechanical role in mediating the relationship between breast size and the postural adaptations to larger breasts[23]. In three studies, muscle function tests in breast-related research[23, 45, 49] have been used. However, in only two of these studies[45, 49] have back extensor muscles been specifically targeted, and in both, manual muscle tests and Kendall's standardised muscle grading scale to measure muscle strength have been used rather measures of endurance.

Benditte et al[45] assessed the strength of back extensor muscles as part of a functional evaluation of the spine (spine score) in women (mean age of 28 years) with different breast

sizes (bra cup size A to ≥DD). In the absence of mean data for back extensor strength, it was not certain how back muscle strength varied across their sample (n=50). However, deficits in muscle strength inflated the 'spine score' and higher scores correlated positively with back pain measured by VAS[45]. This loosely implicated back extensor strength in the symptom pathway for women with large breasts who experienced greater severities of back pain. It was unfortunate that the region of this back pain was also not well-defined in this study.

Chao et al[49] assessed the strength of pectoral muscles, rhomboids and middle and lower trapezius in women aged 18-73 years (n=50) before and after reduction mammoplasty. They provided limited explanation of how testing was isolated to certain muscles or to different regions of the same muscle (trapezius), but did present the mean data and showed a significant improvement in the muscle strength of rhomboids and of middle and lower trapezius alongside low back pain postoperatively. In the absence of a control group in their surgical study, it was difficult to interpret the meaningfulness of the strength data presented and it was unclear how the significant changes in strengths of some upper torso muscles but not others, related to low back pain.

The data presented in this chapter show some consistency with prior research by indicating that larger breasts are related to poorer back muscle function. There is some linearity to the relationship between breast size and upper back extensor muscle endurance, albeit weak, that is indicated in our data and extends what is known more specifically about the relationship between breast size and upper back extensor muscles. Although the reasons for this relationship are not certain, prior research has suggested the important role that upper back extensor muscles could have in counteracting the higher thoracic flexion torques associated with larger breasts[22, 23]. Establishing the relationship between upper back extensor muscle endurance and thoracic flexion torques could be a worthwhile avenue for future research but this needs adequate examination in relation to breast size and UBP to be able to advance theoretical knowledge on breast-related UBP.

Although breast size explained only a small amount of variance in upper back extensor muscle endurance (7%), the relationship between these variables was the strongest out of all of those examined. This was reflected in the odds ratios where changes in upper back extensor endurance for each increment of BSS were the largest recorded.

Thoracic kyphosis is reputed to have a central role in the experience of UBP in women with large breasts[22-24, 27, 53] but the findings of this chapter have identified no discrete relationship between breast size and thoracic kyphosis. This builds on the findings of Chapter 8 where a relationship between thoracic kyphosis and UBP was also questioned. The data we have

generated provide no evidence that supports the biomechanical theory that differences in breast size are related to thoracic kyphosis or that differences in thoracic kyphosis are related to UBP[27]. The robust measures that we employed to assess thoracic kyphosis[255a] strengthens our assertion. In only one previous study by Findikcioglu et al[53] have robust radiological methods to assess thoracic kyphosis in women (18-49 years) of different breast sizes (bra cup size A-D) been used. Unfortunately, despite having an adequate sample size (n=93), they analysed breast size as a categorical variable in their study and it was not clear that a linear relationship existed between breast size and thoracic kyphosis. Whilst Findikcioglu et al[53] demonstrated a difference in thoracic kyphosis between breast size groups, with the greatest angles reported in women with large breasts, it was not certain that breast size alone accounted for these differences. The angles of thoracic kyphosis that ranged from 15-56° (mean angle: 39°) across participants in their study[53], were lower than the angles recorded for our participants which ranged from 17-65° (mean angle 42°). This was more likely attributable to our participants being older (mean age 61 years) than it was to our sample having a greater diversity of breast sizes (bra cup sizes A-HH).

With reference to established norms, the mean thoracic kyphosis angles recorded for our sample were comparably normal[234] and given the sample age, angles were expected to be greater than normal in some cases[11, 12, 82]. The lack of a significant linear relationship between breast size and thoracic kyphosis in our postmenopausal subset provide no reason to believe that pathological angles that were recorded for some participants were the result of them having large breasts. In contrast, Findikcioglu et al[53] who reported no significant effect of age on thoracic kyphosis, showed mean angles of approximately 45° amongst women with large breasts which, given the young average age of their sample (34 years), are considered substantially abnormal[234].

The final important findings of this chapter were the relationships identified between breast size and other anthropometric and body composition characteristics. It is often assumed that women have larger breasts as a result of being overweight. Women presenting for reduction mammoplasty, for example, are often encouraged to lose weight prior to considering surgery. Our findings indicate a strong relationship between breast size and fat mass which corroborates prior accounts[282] and is, perhaps, unsurprising in view of the physiology of breast tissue where fat comprises up to 56% of total breast volume[266]. We also noted that women with larger breasts had more ptotic breasts that also splay further apart. Increased breast breadth (splay) together with increased breast volume, but not breast ptosis, have been previously reported along with age to account for 23% of the variance in upper torso musculoskeletal pain[267]. Although this is a relatively small proportion of explained variance

in physical symptoms, it nevertheless suggests that splay, in addition to size, could be an important breast characteristic to consider in relation to UBP. Our findings would suggest that breast ptosis could also be important as linear relationships with breast size were very strong.

In conclusion, this chapter presents head, upper back and shoulder posture and upper back extensor muscle endurance as physical characteristics associated with breast size. The cross-sectional nature of our work limits us from deliberating a causal relationship between breast size and these characteristics. However, with respect to the possible mechanisms that link these characteristics it seems more likely than not that breast size would be the precursor rather than the consequence in these relationships. As such, breast size, amongst other things, could have a small role in the development of a more forward head posture, a more rounded back and more protracted shoulders. Whether these collective features have a role in UBP is uncertain. Also, because it is unlikely that deficits in upper back extensor muscle endurance itself would lead to larger breasts, we also speculate that increasing breast size leads to reduced upper back extensor muscle endurance. It is however, possible that other characteristics such as physical activity levels may also be involved in this relationship and further prospective work is needed to confirm this.

Chapter 10 Is breast size related to prevalent thoracic vertebral fracture? A cross-sectional study

JBMR PLUS

Is Breast Size Related to Prevalent Thoracic Vertebral Fracture? A Cross-Sectional Study

Linda Spencer,[1] Leanda McKenna,[1] Robyn Fary,[1] Richard Ho,[2] and Kathy Briffa[1]

[1]School of Physiotherapy and Exercise Science, Curtin University, Perth, Western Australia, Australia
[2]Perth Radiological Clinic, Perth, Western Australia, Australia

ABSTRACT

Large breasts may increase the likelihood of thoracic vertebral fractures by increasing the mechanical loading of the spine. We examined breast size as a factor associated with prevalent thoracic vertebral fractures, also considering its relationship with thoracic kyphosis and upper back extensor muscle endurance. Using a cross-sectional study, the design measurements collected were thoracic vertebral fractures ($\geq$20% loss in vertebral body height on lateral radiograph), breast size (bra size converted to an ordinal breast size score), BMD (g/cm^2 averaged femoral neck, DXA), upper back extensor muscle endurance (isometric chest raise test), body composition (DXA), thoracic kyphosis (radiograph), and upper back pain (numerical rating scale). Correlations and multivariable logistic regression examined relationships between characteristics and their association with vertebral fracture. Participants were 117 healthy postmenopausal women. The 17 (15%) women with $\geq$1 thoracic vertebral fracture had larger breast size (mean difference [MD]: 2.2 sizes; 95% CI, 0.6 to 3.8 sizes), less upper back extensor muscle endurance (MD: −38.6 s; 95% CI, −62.9 to −14.3 s), and greater thoracic kyphosis (MD: 7.3°; 95% CI, 1.7° to 12.8°) than those without vertebral fracture. There were no between group differences in age, height, weight, and BMD. Breast size ($r = -0.233$, $p = 0.012$) and thoracic kyphosis ($r = -0.241$, $p = 0.009$) correlated negatively with upper back extensor muscle endurance. Breast size was unrelated to thoracic kyphosis ($r = 0.057$, $p = 0.542$). A (final) multivariable model containing breast size (OR 1.85; 95% CI, 1.10 to 3.10) and thoracic kyphosis (OR 2.04; 95%CI, 1.12 to 3.70) explained 18% of the variance in vertebral fracture. Breast size had a significant, but weak relationship with vertebral fracture ($R^2 = 0.10$), which was independent of BMD and unrelated to thoracic kyphosis. Further work is needed to confirm larger breast size as a risk factor for vertebral fracture. © 2020 The Authors. *JBMR Plus* published by Wiley Periodicals, Inc. on behalf of American Society for Bone and Mineral Research.

KEY WORDS: BIOMECHANICS; FRACTURE RISK ASSESSMENT; DXA; MENOPAUSE

Introduction

Thoracic vertebral fractures have negative consequences for physical function[1–3] and can lead to progressive disability and significant healthcare costs.[4] Postmenopausal women are at greater risk of vertebral fractures.[5] Fracture risk is the function of bone strength and the loads to which it is exposed. Many factors have been associated with fracture risk, with plausible relationships either via effects on bone strength or via loading of the thoracic vertebra.[6] Clear mechanisms for other factors that appear to be related are yet to be determined.

One aspect of the female physique that may contribute to the risk of thoracic vertebral fractures that has not been explicitly investigated is breast size. Larger breast size is associated with a more habitually flexed posture, and greater thoracic kyphosis and upper back pain.[7–10] Breast size also accounts for up to 29% of the variance in trunk muscle activity,[9] and increasing breast weight magnifies compressive forces on the thoracic spine.[11] It follows that large heavy breasts could heighten the vulnerability of women to vertebral fractures.

In this exploratory study, we examined the relationships between prevalent thoracic vertebral fractures and breast size, thoracic kyphosis, and upper back extensor muscle endurance in healthy postmenopausal women.

Materials and Methods

Participants were initially recruited for a larger survey-based study examining relationships between physical characteristics and upper back pain in postmenopausal women. The need for volunteers was advertised via radio, newspaper, and online. Advertising was designed to attract women of all breast sizes

with and without upper back pain. To be included in the survey, sample volunteers were required to reside in Australia, to read and understand English, and be aged ≥40 years. Exclusion criteria were past history of breast surgery or thoracic spine surgery; systemic inflammatory conditions; neurodegenerative disorders; any known pathology of the breast, lung, or thoracic spine; or recent or long-term use of steroid or pain medication. From the 269 participants recruited for the survey, consecutive postmenopausal women who provided their contact details were invited to participate further and undergo objective measures. Women who classified themselves as postmenopausal and reported their last menstrual period was more than 12 months previously were defined as postmenopausal. The target was to have a sample of 100 women: 50 who reported upper back pain and 50 without upper back pain. The study was approved by the Human Research Ethics Committee at Curtin University (RDHS-267-15); all participants provided written informed consent.

Data regarding medical history and the presence (yes/no) and severity (numerical rating scale [NRS]) of upper back pain within the previous month were collected in the survey study using an online questionnaire (version June 2016; Qualtrics, Provo, UT, USA). Upper back pain was defined as pain in the spine region above the base of the rib cage and below the neck.

Objective data were collected at a university health clinic by an experienced, female musculoskeletal physiotherapist who had completed over 50 hours of training and practice of the methods used. The physiotherapist was not aware of the individual participant's questionnaire data at the time objective testing was conducted. Participants' height (cm) and weight (kg) were objectively measured and used to calculate BMI (kg/m^2). Other physical measures included breast size, BMD, body composition, and upper back extensor muscle endurance. The radiographic assessments of thoracic kyphosis and prevalent vertebral fractures were completed at local branches of a large radiological practice. Participants were referred for a single X-ray after completing all other physical measures.

Breast size was determined using a traditional measure of bra size that included underbust and overbust measures.[12] Triplicate measurements of under bust (intraclass correlation coefficient [ICC] 0.999; 95% CI, 0.996 to 0.999) and overbust (ICC 0.881; 95% CI, 0.770 to 0.947) circumference in 20 women aged ≥40 years showed good to excellent reliability. Bra sizes[13] were converted into a continuous breast size score (BSS) between 0 to 18 (Supplemental Fig. S1) using a system conceptually similar to sizing breast prostheses following unilateral mastectomy[14] that has been used in prior research.[15] Using this system, a 1-cupsize increase (eg, C to D) on the same band size (under bust, eg, size 12) is equivalent to a 1-point increase in BSS. Similarly, a one-band-size increase (eg, 12 to 14) with no change in cup size is also a 1-point increase in BSS.

BMD and body composition were assessed using DXA. Scans were performed using a Lunar Prodigy device (Model DPX 8743) with Encore software (GE Healthcare, Little Chalfont, UK). Standard quality assurance tests, including calibration measurement using a phantom spine, were completed daily prior to use according to the manufacturer's guidelines. The average BMD (g/cm^2) of the left and right femoral necks (FNs) was calculated and used as the measure of BMD. Duplicate scans of 11 women conducted by our operator within a 12-month period showed excellent intrarater reliability (ICC 0.974; 95% CI, 0.908 to 0.993) and a coefficient of variation of 1.3%.

Body composition was assessed using whole-body scans with participants in a supine position. Total fat mass (kg) and lean

mass (kg) were recorded. All scans were checked immediately after acquisition and later reviewed by a study supervisor with over 20 years of experience.

Upper back extensor muscle endurance was assessed using the isometric chest raise test.[16] Participants were positioned prone over a wedge cushion (Lunamumma, VIC, Australia) with their navel level with the highest edge of the cushion. Adjustable straps were used to secure participants' pelvis and feet to the bed. With their arms unsupported and hands at their temples, participants were asked to raise their chest clear of the bed and hold this position for as long as possible.[15] A stopwatch was used to measure the time (in seconds) to failure, defined as the point at which the chest touched the bed. Participants who were unable to raise their chest to initiate the test were allocated a time of zero. An upper limit cut-off time of 300 s was imposed.[15] The isometric chest raise test has high reliability (ICC 0.93 to 0.97) and reproducibility (r = 0.94 to 0.9.5) when used with women (aged 35 to 49 years) with and without chronic back pain.[16]

A single lateral X-ray of each participant was obtained using standardized instructions. Participants were positioned standing with their arms elevated to approximately 90 degrees. X-ray devices were positioned at a film focus distance of 120 cm with the beam centered on the midthoracic vertebrae. The X-ray was evaluated by one radiologist (RH) blinded to the aims of the study. Thoracic kyphosis (°) was measured using the four-segment vertebral centroid global angle method as previously described.[17] The midpoints of the upper two (T1, T2) and lowest two (T11, T12) most clearly visible thoracic vertebral bodies were used to determine the vertebral centroid angles using digital software (InteleViewer, Inteleard, Montreal, Canada). Prevalent vertebral fractures were identified as those vertebrae with a 20% reduction in vertebral body height relative to normal adjacent vertebrae.[18] The radiologist (RH) completed all assessments without any clinical information about each participant.

Statistical analysis

A priori sample size calculation indicated that our sample of 117 would be sufficient to detect a minimum change in odds for prevalent vertebral fracture of 0.62 with 80% power and a confidence level of 95%.[19]

Descriptive summaries were calculated for all participant characteristics and included means and standard deviations for continuous data and frequency distributions for categorical data. The sample was dichotomized into vertebral fracture (participants with ≥1 vertebral fracture) and nil vertebral fracture groups. Independent samples t tests or chi-square analyses were used to compare participant characteristics.

To explore the relationships between the independent variables of breast size, thoracic kyphosis, and upper back extensor muscle endurance, Pearson's correlation coefficients (r) were calculated. The strength of relationships were interpreted as weak (r ≤ 0.25), fair (r = 0.25 to 0.5), moderate (r = 0.50 to 0.75), or strong (r > 0.75).[20] Logistic regression models were used to examine the association between these characteristics and the dependent variable prevalent vertebral fracture (yes/no). Results were summarized using ORs and 95% CIs. All ORs were standardized by calculating them for a 1-SD change in the variable of interest. Bivariate models were examined prior to conducting a multivariable logistic regression analysis where all independent variables of interest (breast size, thoracic kyphosis, and upper back extensor muscle endurance) were examined together.

151

Bivariate models were tested with and without adjustment for age and BMD. Variations of the multivariable model that were examined included adjustment for BMD in step 1, and the model with and without thoracic kyphosis. Three interaction terms were also explored in the multivariable model (breast size * thoracic kyphosis, breast size * upper back extensor muscle endurance, thoracic kyphosis * upper back extensor muscle endurance). The final and most optimal model was built using backward conditional procedures and contained only those variables making a significant contribution ($p < 0.05$). The assumptions (linearity of independent variables and log odds, absence of multicollinearity and outliers) of the model were checked.

Data were analyzed using SPSS version 24 (SPSS, Inc., Chicago, IL, USA). All hypothesis tests were two-sided and p-values <0.05 were considered statistically significant.

Results

The data of 117 postmenopausal women who had completed all relevant measures were analyzed (Fig. 1). Participant characteristics are summarized in Table 1. Seventeen (15%) participants had radiological evidence of ≥1 vertebral fracture. Two participants (one from each group) had osteoporosis with a left FN T-score of ≤ −2.5. Osteopenia (left FN T-score −2.5 to −1) was identified in 47 (40%) participants, and 6 (13%) from the vertebral fracture group. Vertebral fractures were located in the mid to lower thoracic spine (Table 1). Thirteen (76%) participants in the fracture group reported having upper back pain compared with 47 (47%) participants in the nil fracture group ($p = 0.025$). All participants were able to lift their chest off the bed and three participants reached the upper limit threshold of 300 s when measuring upper back extensor muscle endurance using the isometric chest raise test.

Breast size scores ranged from 2 to 18 (equivalent to Australian bra sizes 10A to 26H). Median (interquartile range [IQR]) underbust and overbust circumferences were 87.0 cm (11.8 cm) and 102 cm (16.0 cm) and the median (IQR) breast size score of 7.0 (4.0), equivalent to a bra size of, for example, 16C. The average equivalent bra size of participants with vertebral fracture was 16DD (BSS = 9). This was two sizes larger than the average equivalent bra size of participants without fracture (16C/BSS = 7). For other equivalent bra sizes, see supplementary Fig. S1.

Participants with prevalent vertebral fracture(s) had significantly larger breasts, less upper back extensor muscle endurance, and greater thoracic kyphosis compared with those without vertebral fracture (Table 1). There were no differences in age, height, weight (total lean or fat), or BMD between the fracture and nil fracture groups (Table 1).

There were weak negative relationships between breast size and upper back extensor muscle endurance ($r = -0.233$, $p = 0.012$), and between thoracic kyphosis and upper back extensor muscle endurance ($r = -0.241$, $p = 0.009$); however, breast size was not correlated to thoracic kyphosis ($r = 0.057$, $p = 0.542$).

Each of the three variables of interest was associated with prevalent vertebral fracture (Table 2). Neither age nor BMD were associated with prevalent vertebral fracture and adjusting for them made little difference to any of these associations.

The final and most optimal multivariable model included breast size and thoracic kyphosis (Table 3). This model was statistically significant, $\chi^2(2)$ 12.5, $p = 0.002$, and explained a total of 18% (Nagelkerke R^2) of the variance in vertebral fracture (Table 3). Breast size made a small significant contribution to the model, accounting for 10% of this variance. Upper back extensor muscle endurance did not improve the variance explained by model when included ($p = 0.085$) and BMD, when entered in step 1, was not significant ($p = 0.665$).

Changes to the model structure (with and without BMD and/or thoracic kyphosis) did not change the contribution made by breast size, which remained significant, but weak with R^2 consistent at 0.10. The inclusion of thoracic kyphosis in the model had negligible influence on the association between breast size
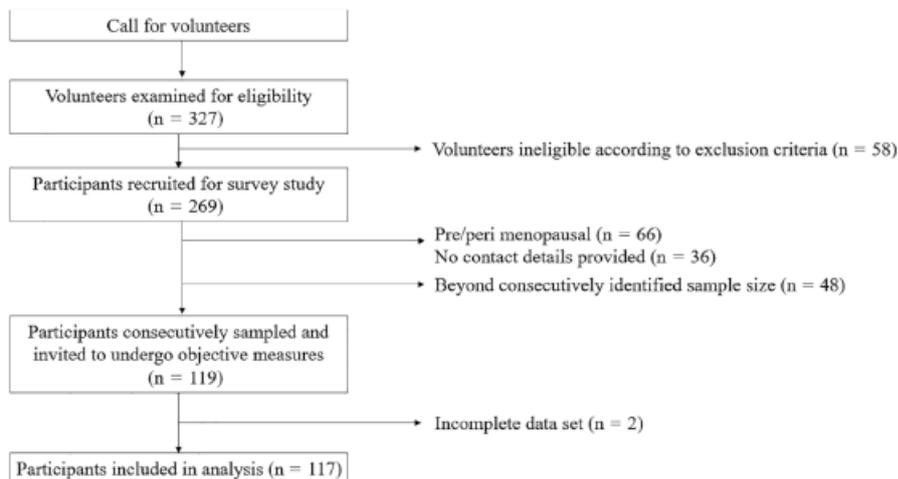
Fig. 1. Participant recruitment to the study.

152

Table 1. Descriptive Summary of Sample

Participant characteristics Mean (SD)	Total (n = 117)	Nil fracture (n = 100)	Fracture (n = 17)	MD (95% CI)	p-Value
Age (years)	61.4 (7.0)	61.6 (7.1)	60.4(6.8)	−1.3 (−4.9 to 2.4)	0.496
Height (cm)	161.3 (6.2)	161.2 (6.4)	161.5 (4.6)	0.3 (−3.0 to 3.5)	0.874
Weight (kg)	75.4 (15.3)	74.4 (14.3)	81.1 (19.2)	6.7 (−1.2 to 14.6)	0.095
BMI (kg/m²)	29.0 (5.5)	28.6 (5.0)	31.1 (7.5)	2.5 (−1.4 to 6.5)	0.198
Fat mass (kg)	31.9 (10.3)	31.7 (10.0)	33.2 (12.2)ᵃ	1.6 (−4.0 to 7.1)	0.578
Lean mass (kg)	40.5 (5.8)	40.3 (5.8)	42.4 (5.8)ᵃ	2.1 (−0.9 to 5.2)	0.170
Breast size (breast size score)	7.9 (2.5)	6.8 (2.8)	8.9 (4.3)	2.2 (0.6 to 3.8)	0.008
BMD (femoral neck) (g/cm²)	0.907 (0.113)	0.906 (0.109)ᵇ	0.909 (0.142)	−0.004 (−0.056 to 0.063)	0.898
BMD Femoral neck (age adjusted Z-score)	0.349 (0.815)	0.366 (0.796)ᵇ	0.253 (0.937)	−0.113 (−0.538 to 0.313)	0.602
Thoracic kyphosis centroid angle (°)	42.2 (10.9)	41.2 (10.4)	48.4 (12.0)	7.3 (1.7 to 12.8)	0.011
Upper back extensor muscle endurance (s)	97.1 (70.7)	102.7 (73.4)	64.1 (39.2)	−38.6 (−62.9 to −14.3)	0.003
Upper back pain NRS scores	2.3 (2.7)	2.1 (2.8)	3.4 (2.2)	1.3 (−0.1 to 2.7)	0.076
Fracture characteristics (n = 17)	Frequency (%)				
Participants with 1 vertebral fracture	11 (64)				
Participants with 2 vertebral fractures	4 (24)				
Participants with 3 vertebral fractures	2 (12)				
Fracture locations (n = 25 fractures in 17 participants)	Frequency (%)				
T1 to T5	0 (0)				
T6	2 (8)				
T7	5 (20)				
T8	6 (24)				
T9	1 (4)				
T10	1 (4)				
T11	5 (20)				
T12	5 (20)				

ᵃOne missing value.
ᵇTwo missing values.
NRS = numerical rating scale; MD = mean difference.

Table 2 Associations Between the Independent Variables of Interest and Prevalent Vertebral Fracture in Bivariate Analysis (Logistic Regression)

Independent variable	n	Unit of comparison (equivalent to 1 SD)	OR (95% CI)	p-Value
Age (years)	117	+7.0 years	0.83 (0.50–1.40)	0.492
BMD (femoral neck) (g/cm²)ᵃ	115	−0.113 g/cm²	0.97 (0.58–1.62)	0.897
Breast size (breast size score)	117	+2.5 BSS sizes	1.89 (1.15–3.11)	0.013
Thoracic kyphosis centroid angle (°)	117	+10.9°	2.11 (1.16–3.83)	0.014
Upper back extensor muscle endurance (s)	117	−70.7 s	2.23 (1.00–4.94)	0.046

ᵃTwo missing values because of bilateral total hip prostheses.
BSS = breast size score.

and prevalent vertebral fracture. With thoracic kyphosis excluded from the model, upper back extensor muscle endurance remained nonsignificant.

Interaction terms between breast size and upper back extensor muscle endurance ($p = 0.815$), between breast size and thoracic kyphosis ($p = 0.234$), and between thoracic kyphosis and upper back extensor muscle endurance ($p = 0.143$) were not associated with the outcome prevalent vertebral fracture and the final multivariable model remained virtually unchanged in each case.

Discussion

In this study, we found that healthy postmenopausal women with larger breast size are more likely to have prevalent vertebral fractures. The relationship between breast size and vertebral fracture, albeit weak, has been identified to be independent of BMD, age, thoracic kyphosis, and upper back extensor muscle endurance.

There could be a biomechanical rationale linking larger breasts to the presence of vertebral fractures, but breast size

153

Table 3 Factors Associated With Prevalent Vertebral Fracture in Multivariable Analysis (Final Model)

Independent variable	n	Unit of comparison (equivalent to 1 SD)	OR (95% CI)	p-Value
Breast size (BSS)	117	+2.5 BSS sizes	1.85 (1.10–3.10)	0.020
Thoracic kyphosis centroid angle (°)	117	+10.9°	2.04 (1.12–3.70)	0.020

Note. Model was run backward conditional (p for inclusion <0.05) with forward conditional confirming the results.
BSS = breast size score.

has not been previously considered as an associated risk factor for prevalent vertebral fractures. Breast size is a physical characteristic that, by increasing the forces acting on the spine,[11] may influence the biomechanical loads to which the spine is exposed. As such, it is possible that breast size may be interacting with other factors within the local environment of the vertebral body that affects its integrity.[6]

Thoracic flexion torques are reported to be up to 5 times greater in women with large breasts compared with women with small breasts.[8,21] It is possible that with greater thoracic flexion torques there are greater vertebral compression loads,[22,23] which could increase the risk for vertebral fractures.[6] Some previous accounts show that large breasts are associated with greater thoracic kyphosis,[7,8] an important factor generating greater thoracic flexion torques and increasing vertebral compression loads.[22,23] These findings provided a rationale for exploring the possibility of a relationship between breast size, thoracic kyphosis, and vertebral fracture.

Although thoracic kyphosis was associated with vertebral fracture, we did not find an association between breast size and thoracic kyphosis. This was an unexpected finding, but with good heterogeneity in terms of breast size and thoracic kyphosis, we have no reason to doubt it. Interestingly, a recently published larger study (n = 300) also reported that breast size was unrelated to thoracic kyphosis.[21] Given the cross-sectional design of our study, it is not possible to determine whether thoracic kyphosis contributed to the risk of incident vertebral fractures (detected as prevalent fractures in our sample) or whether kyphosis was a consequence of the prevalent vertebral fractures. As we found no significant interactions suggesting that the relationship between breast size and vertebral fracture depended on the degree of thoracic kyphosis, it appears they are independent relationships in our group of healthy postmenopausal women. Longitudinal studies to determine the temporal relationship between breast size, thoracic kyphosis, and fracture risk are required to determine causality.

BMD was comparable between the fracture and nil fracture groups. In the context of our selection criteria, excluding volunteers with diagnosed osteoporosis or known vertebral fractures (known pathology of the thoracic spine), this finding was less surprising than it would have been in a community-based sample. On average, the BMD Z-scores (age-adjusted) in our sample sit slightly above the population-based mean of zero, and the prevalence of osteoporosis was less than would be expected from epidemiological evidence.[24] Of interest, however, despite the exclusion criteria, the prevalence of vertebral fractures in our sample was 15%, which is consistent with rates reported for women aged over 50 years in two large population studies.[25,26] The lack of association between BMD and prevalent fracture suggests that the vertebral fractures were not specifically a feature of poor vertebral strength. Although we acknowledge that aspects of bone strength not assessed by areal BMD cannot be ruled out

in our study, it may be that factors related to vertebral loading provide the biomechanical basis for the relationship between breast size and vertebral fracture.

Upper back extensor muscle endurance was considered in the current study to be a suitable marker of trunk muscular support and was investigated to explore speculation that it has an important role in offsetting the biomechanical burden of larger breasts and in mitigating the progression of thoracic kyphosis and consequent upper back pain.[8] Our correlational analysis supports this speculation by showing a significant negative relationship between upper back extensor muscle endurance and breast size and between upper back extensor muscle endurance and thoracic kyphosis.

The endurance capacity of upper back muscles was considered particularly important to a biomechanical relationship involving breast size, thoracic kyphosis, and thoracic vertebral fractures given the high prevalence of slow twitch (type I) fibers in the erector spinae of the upper back, which suggests these are postural muscles responsible for slow and sustained contractions.[27] Trunk muscles have been previously discussed as an important feature implicated with the presence of vertebral fractures in postmenopausal women.[28,29] Highlighting this importance are the losses in size and density of important spine stabilizing muscles that occur more profoundly in women than in men with advancing age.[30] Trunk muscles could affect vertebral loading and fracture risk by relating to thoracic kyphosis,[31–33] but it cannot be assumed that declining thoracic musculature with aging alone will increase thoracic kyphosis.[34] Upper back extensor muscles with better endurance provide the spine with better stability, creating less loading on the intervertebral joints[35] and reducing skeletal and ligamentous strain.[36] In the presence of an accentuated thoracic kyphosis, however, the capability of upper back extensor muscles to generate force over time may be affected by the length-tension relationships of these muscles.[6] This decrease in capability may explain the negative relationship we have identified and why vertebral fractures were more likely in women with greater thoracic kyphosis and those with poorer upper back extensor muscle endurance.

Our bivariate analysis findings of an association between upper back extensor muscle endurance and prevalent vertebral fractures is consistent with the protective role accorded to the upper back extensor muscles in previous studies of vertebral fracture.[28,33] Although the contribution of upper back extensor muscle endurance was not significant in our final multivariable model, it is important to highlight that both breast size and thoracic kyphosis independently reduced the strength of the relationship between upper back extensor muscle endurance and prevalent vertebral fracture. The decreasing OR for upper back extensor muscle endurance in the presence of breast size and thoracic kyphosis within the multivariable model for vertebral fracture perhaps reflects the antagonistic relationship between upper back extensor muscle endurance and each of these

154

variables, respectively. The interplay between these variables would be worthy of consideration in future studies looking at training upper back extensor muscle endurance to reduce the risk of vertebral fractures, particularly in women with large breasts. For the likelihood of vertebral fracture, however, it appears that breast size and thoracic kyphosis are not influenced strongly by upper back extensor muscle endurance.

In this study, we present breast size as a new and novel characteristic associated with vertebral fracture. Women with larger breasts were more likely to have prevalent vertebral fractures with odds that are comparable to other characteristics previously reported.[37,38] Our findings suggest that, unrelated to BMD and thoracic kyphosis, vertebral facture may turn out to be an important clinical consequence of large breasts, which may account for why upper back pain is more common in women with large breasts.[8,10,39] Back pain has previously been related to the severity and number of prevalent[3] and incident[2] vertebral fractures in women with osteoporosis. Our findings indicate that upper back pain was more likely in participants with vertebral fractures compared with those without, but that the severity of this pain was not significantly different between groups. Pain severity was described by the fracture group as being mild (NRS <4)[40] however, it is possible that owing to the small size of the fracture group, there was not a sufficient spread across the range of possible severity scores. This may have made it difficult for us to find a significant difference in upper back pain severity between groups. Future research might look at other samples of women to establish if vertebral fractures are related to the symptomatic burden in those with large breasts.

One limitation of our study is that the definition of vertebral fracture we used is only one of several that are available;[18,41–43] other definitions may have yielded different results. The precise measurement of intact breast size is notoriously difficult because of the complex and varied morphology of the breast.[44] To date, there is no perfectly valid noninvasive method for measuring breast size, and this is a challenge for all nonsurgical studies in this clinical area. For the purposes of this study, we selected a breast size scoring method that allowed us to rank the breast size of our participants. This was sufficient to identify the relationship between breast size and prevalent vertebral fracture, but does not enable examination of precise volumes that may or may not be problematic.

In conclusion, the relationship between breast size and vertebral fracture is identified in this study to be weak. Breast size accounted for only a small proportion of explained variance in prevalent vertebral fracture. Other physical characteristics and established risk factors,[37,38] which have not been assessed in this study, are likely to explain the remaining variance. Consequently, breast size needs to be further examined alongside these other characteristics and risk factors to confirm breast size as a potential risk factor for vertebral fracture.

Disclosures

The authors have nothing to disclose.

Acknowledgments

References

1. Huang C, Ross PD, Wasnich RD. Vertebral fractures and other predictors of back pain among older women. J Bone Miner Res. 1996;11(7): 1026–32.

2. Nevitt MC, Ettinger B, Black DM, et al. The association of radiographically detected vertebral fractures with back pain and function: a prospective study. Ann Intern Med. 1998;128(10):793–800.

3. Johansson L, Sundh D, Nilsson M, Mellstrom D, Lorentzon M. Vertebral fractures and their association with health-related quality of life, back pain and physical function in older women. Osteoporos Int. 2018;29(1):89–99.

4. Kanis JA, World Health Organisation Scientific Group. Assessment of Osteoporosis at the Primary Health-Care Level: WHO Technical Report. WHO Collaborating Centre for Metabolic Bone Diseases. Sheffield, UK: University of Sheffield; 2007.

5. Anagnostis P, Siolos P, Gkekas NK, et al. Association between age at menopause and fracture risk: a systematic review and meta-analysis. Endocrine. 2019 Feb;63(2):213–24.

6. Briggs A, Greig AM, Wark JD, Fazzalari NL, Bennell KL. A review of anatomical and mechanical factors affecting vertebral body integrity. Int J Med Sci. 2004;1(3):170–80.

7. Findikcioglu K, Findikcioglu F, Ozmen S, Guclu T. The impact of breast size on the vertebral column: a radiologic study. Aesthetic Plast Surg. 2007;31:23–7.

8. McGhee D, Coltman KA, Riddiford-Harland DL, Steele JR. Upper torso pain and musculoskeletal structure and function in women with and without large breasts: a cross sectional study. Clin Biomech. 2018;51: 99–104.

9. Schinkel-Ivy A, Drake JD. Breast size impacts spine motion and postural muscle activation. J Back Musculoskelet Rehabil. 2016;29(4): 741–8.

10. Coltman CE, Steele JR, McGhee DE. Can breast characteristics predict upper torso musculoskeletal pain? Clin Biomech. 2018;53:46–53.

11. Hansraj KK. Breast forces on the spine. Surg Technol Int. 2016;28: 311–5.

12. Zheng R, Yu W, Fan J. Breast measurement and sizing. In Yu W, Fan J, Harlock SC, Ng SP, eds. Innovation and technology of women's intimate apparel. Cambridge, UK: Woodhead Publishing; 2006 pp 28–58.

13. Berlei. Australian bra sizes. Sydney, Australia: Berlei; 2018 [cited Oct 2015]. Available from: https://www.berlei.com.au/size-charts.

14. Ameona. Breast form fitting guide. Fitzroy North, VIC, Australia: Ameona; 2017 [cited Oct 2015]. Available from: http://www.amoena.com/au/about-us/breast-form-fitting-guide.

15. Spencer L, McKenna L, Fary R, Jacques A, Briffa K. Upper back pain in postmenopausal women and associated physical characteristics. PLoS One. 2019;14(7):e0220452. https://doi.org/10.1371/journal.pone.0220452.

16. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. Arch Phys Med Rehabil. 1996;77(1):75–9.

17. Spencer L, Fary R, McKenna L, Ho R, Briffa K. Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods. Osteoporos Int. 2019 Oct;30(10):2009–18.

18. Griffith JF. Identifying osteoporotic vertebral fracture. Quant Imaging Med Surg. 2015;5(4):592–602.

155

19. Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Behav Res Methods. 2009;41(4):1149–60.

20. Portney L, Watkins M. Foundations of clinical research: applications to practice. 3rd ed. Upper Saddle River, NJ: Pearson/Prentice Hall; 2009.

21. Coltman CE, Steele JR, McGhee DE. Effect of breast size on upper torso musculoskeletal structure and function: a cross-sectional study. Plast Reconstr Surg. 2019;143:686–95.

22. Briggs A, van Dieën JH, Wrigley TV, et al. Thoracic kyphosis affects spinal loads and trunk muscle force. Phys Ther. 2007;87(5):595–607.

23. Bruno AG, Anderson DE, D'Agostino J, Bouxsein ML. The effect of thoracic kyphosis and sagittal plane alignment on vertebral compressive loading. J Bone Miner Res. 2012;27(10):2144–51.

24. Henry MJ, Pasco JA, Nicholson GC, Seeman E, Kotowicz MA. Prevalence of osteoporosis in Australian women: Geelong osteoporosis study. J Clin Densitom. 2000;3(3):261–8.

25. O'Neill TW. The relationship between bone density and incident vertebral fracture in men and women. J Bone Miner Res. 2002;17(12):2214–21.

26. Waterloo S, Ahmed LA, Center JR, et al. Prevalence of vertebral fractures in women and men in the population-based Tromsø study. BMC Musculoskelet Disord. 2012;13:3.

27. Mannion AF, Dumas GA, Cooper RG, Espinosa FJ, Faris MW, Stevenson JM. Muscle fibre size and type distribution in thoracic and lumbar regions of erector spinae in healthy subjects without low back pain: normal values and sex differences. J Anat. 1997;190:505–13.

28. Sinaki M, Itoi E, Wahner HW, et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone. 2002;30:836–41.

29. Mokhtarzadeh H, Anderson DE. The role of trunk musculature in osteoporotic vertebral fractures: implications for prediction, prevention, and management. Curr Osteoporos Rep. 2016;14(3):67–76.

30. Johannesdottir F, Allaire B, Anderson DE, Samelson EJ, Kiel DP, Bouxsein ML. Population-based study of age- and sex-related differences in muscle density and size in thoracic and lumbar spine: the Framingham study. Osteoporos Int. 2018;29(7):1569–80.

31. Granito RN, Aveiro MC, Rennó ACM, Oishi J, Driusso P. Degree of thoracic kyphosis and peak torque of trunk flexors and extensors among healthy women. Rev Bras Ortop. 2014;49(3):286–91.

32. Mika A, Unnithan VB, Mika P. Differences in thoracic kyphosis and in back muscle strength in women with bone loss due to osteoporosis. Spine. 2005;30:241–6.

33. Sinaki M, Wollan PC, Scott RW, Gelczer RK. Can strong back extensors prevent vertebral fractures in women with osteoporosis? Mayo Clin Proc. 1996;71(10):951–6.

34. Lorbergs AL, Allaire BT, Yang L, et al. A longitudinal study of trunk muscle properties and severity of thoracic kyphosis in women and men: the Framingham study. J Gerontol A Biol Sci Med Sci. 2019 Feb 15;74(3):420–7.

35. Goel VK, Kong W, Han JS, Weinstein J, Gilbertson L. A combined finite element and optimization investigation of lumbar spine mechanics with and without muscles. Spine. 1993;18:1531–41.

36. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech. 1996;11:1–15.

37. Nevitt MC, Cummings SR, Stone KL, et al. Risk factors for a first-incident radiographic vertebral fracture in women ≥65 years of age: the study of osteoporotic fractures. J Bone Miner Res. 2005;20(1):131–40.

38. Waterloo S, Nguyen T, Ahmed LA, et al. Important risk factors and attributable risk of vertebral fractures in the population-based Tromso study. BMC Musculoskelet Disord. 2012;13:163.

39. Spencer L, Briffa K. Breast size, thoracic kyphosis & thoracic spine pain - association & relevance of bra fitting in post-menopausal women: a correlational study. Chiropr Manual Ther. 2013;21(20):1–8.

40. Boonstra AM, Stewart RE, Köke AJA, et al. Cut-off points for mild, moderate, and severe pain on the numeric rating scale for pain in patients with chronic musculoskeletal pain: variability and influence of sex and catastrophizing. Front Psychol. 2016;7:1466–6.

41. Eastell R, Cedel SL, Wahner HW, Riggs BL, Melton LJ 3rd. Classification of vertebral fractures. J Bone Miner Res. 1991;6(3):207–15.

42. McCloskey EV, Spector TD, Eyres KS, et al. The assessment of vertebral deformity: a method for use in population studies and clinical trials. Osteopor Int. 1993;3(3):138–47.

43. Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res. 1993;8(9):1137–48.

44. McGhee DE, Steele J. Breast volume and bra size. Int J Cloth Sci Technol. 2011;23:351–60.

156

Supplemental Material

	Cup size	Band size (under-bust circumference, cm)									
		8 (63-67)	10 (68-72)	12 (73-77)	14 (78-82)	16 (83-87)	18 (88-92)	20 (93-97)	22 (98-102)	24 (103-107)	26 (108-112)
Breast size score (over-bust circumference, cm)	AA	0 (75-77)	1 (80-82)	2 (85-87)	3 (90-92)	4 (95-97)	5 (100-102)	6 (105-107)	7 (110-112)	8 (115-117)	9 (120-122)
	A	1 (77-79)	2 (82-84)	3 (87-89)	4 (92-94)	5 (97-99)	6 (102-104)	7 (107-109)	8 (112-114)	9 (117-119)	10 (122-124)
	B	2 (79-81)	3 (84-86)	4 (89-91)	5 (94-96)	6 (99-101)	7 (104-106)	8 (109-111)	9 (114-116)	10 (119-121)	11 (124-126)
	C	3 (81-83)	4 (86-88)	5 (91-93)	6 (96-98)	7 (101-103)	8 (106-108)	9 (111-113)	10 (116-118)	11 (121-123)	12 (126-128)
	D	4 (83-85)	5 (88-90)	6 (93-95)	7 (98-100)	8 (103-105)	9 (108-110)	10 (113-115)	11 (118-120)	12 (123-125)	13 (128-130)
	DD	5 (85-87)	6 (90-92)	7 (95-97)	8 (100-102)	9 (105-107)	10 (110-112)	11 (115-117)	12 (120-122)	13 (125-127)	14 (130-132)
	E	6 (87-89)	7 (92-94)	8 (97-99)	9 (102-104)	10 (107-109)	11 (112-114)	12 (117-119)	13 (122-124)	14 (127-129)	15 (132-134)
	F	7 (89-91)	8 (94-96)	9 (99-101)	10 (104-106)	11 (109-111)	12 (114-116)	13 (119-121)	14 (124-126)	15 (129-131)	16 (134-136)
	G	8 (91-93)	9 (96-98)	10 (101-103)	11 (106-108)	12 (111-113)	13 (116-118)	14 (121-123)	15 (126-128)	16 (131-133)	17 (136-138)
	H	9 (93-95)	10 (98-100)	11 (103-105)	12 (108-110)	13 (113-115)	14 (118-120)	15 (123-125)	16 (128-130)	17 (133-135)	18 (138-140)

Supplemental material. Breast Size Score (BSS) Conversion Chart[a]

[a] To determine a breast size score first identify the correct bra size (band and cup size). Establish the correct band size by measuring around the body, directly below the bust (under-bust circumference) and the correct cup size by measuring across the fullest part of the breasts whilst wearing a bra (over-bust circumference)[13]. Use the top row of the table to select the band size, this increases from left to right. Then use the first column of the table to select the cup size, this increases from top to bottom. Track down and across to find the table cell where these two selections intersect. Breast size score is shown in bolded text.

Attribution Statement							
Co-authored publication	Conception, design and methodology	Implementation of the methodology and acquisition of data	Data analysis	Interpretation and discussion	Writing of original draft	Review and editing	Final approval
Chapter 10. Is breast size related to prevalent vertebral fracture? A cross-sectional study.							
Thesis Candidate: Linda Spencer	✓	✓	✓	✓	✓	✓	✓
Thesis Candidate Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 1: Dr Leanda McKenna	✓	✓		✓		✓	✓
Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 2: Dr Robyn Fary	✓			✓		✓	✓
Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 3: Dr Richard Ho		✓		✓			✓
Co Author 3 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 4: Dr Kathy Briffa	✓		✓	✓		✓	✓
Co Author 4 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Chapter 11 Upper back musculoskeletal tissue sensitivity, breast size and upper back pain

Abstract

Objectives: The physiological basis for upper back pain experienced by women with large breasts is unclear but could relate to sensitivity of musculoskeletal tissues strained from the postural adaptations to large breasts. The aim of this cross-sectional study was to examine if breast size and upper back pain were associated with greater sensitivity of upper back musculoskeletal tissues. **Methods:** 119 healthy postmenopausal women (mean age 61 years) had their breast size (breast size score, BSS), upper back pain (numerical rating scale, NRS), and upper back tissue sensitivity (pressure pain thresholds (PPTs) (digital algometry, kPa) assessed. The PPTs of six skeletal sites (T2, T4, T6, T8, T10 and T12) and six muscular sites (pectoralis major, levator scapulae, sternocleidomastoid, and upper, middle and lower trapezius muscles) were examined. Linear mixed models with random subject effects were used to evaluate differences in sensitivity at each anatomical site between participants grouped by breast size (small (BSS<7), large (BSS≥7)) and upper back pain (nil-mild (NRS<4), moderate-severe (NRS≥4)). **Results:** For most sites the differences in sensitivity between upper back pain groups were highly significant (p<0.002) with significantly lower PPTs (MD: 74.6-151.1kPa) recorded for participants with moderate-severe upper back pain. There were no differences in sensitivity between breast size groups. **Discussion:** Increased upper back musculoskeletal sensitivity is related to upper back pain but not to breast size. This evidence suggests that strain on musculoskeletal tissues due to large breasts is unlikely to be a physiological basis for upper back pain in women.

Key words:

Breast size, upper back pain, musculoskeletal tissue sensitivity, pressure pain thresholds.

Introduction

Upper back pain is a common complaint amongst women with large breasts.[1-5] The physiological explanation for this pain remains unclear but could relate to the strain placed on musculoskeletal tissues that arises from the postural adaptations associated with large heavy breasts.[6]

A forward head, rounded upper back and protracted shoulders are postural adaptations that are considered typical in women with large breasts.[6] Although speculative, the pull of large heavy breasts on the anterior chest wall that causes the forward displacement of the body's center of gravity is thought to explain the characteristic changes in sagittal spine alignment that contribute to these postural adaptations. Robust radiographic methods have been used to demonstrate that cervical lordosis and thoracic kyphosis angles are abnormally greater in women with large breasts.[7-9] Nevertheless, these trends have only been consistently observed in women with very large breasts awaiting reduction mammoplasty.[7-9] There is accumulating evidence that there are biomechanical implications of having large breasts, and these include that thoracic flexion torques are magnified[2, 10] and vertebral compression loads are higher.[11] These findings support the theory that structural and mechanical factors related to breast size have the potential to mechanically overload musculoskeletal structures such as intervertebral joints,[12] vertebral bodies,[13] cervicoscapular muscles[6] and back extensor muscles,[2] which could lead to increased musculoskeletal tissue pain sensitivity, causing upper back pain.[6]

Although it is plausible that sensitized musculoskeletal tissues could account for upper back pain in women with large breasts, this has not been previously investigated. With the limited direct examination of musculoskeletal tissues in the upper back it remains difficult to confirm that breast size, via putative biomechanical mechanisms, contributes to the tissues becoming symptomatic. Furthermore, whilst it might be expected that locally sensitized tissues would be linked to subjective reports of upper back pain, this also remains unexplored. Examining pain sensitivity in musculoskeletal tissues with respect to breast size and upper back pain may provide helpful insight into the upper back pain experience of women with large breasts and enhance our understanding of underlying pain mechanisms.

Digital algometry is a reliable method of measuring localized tissue pain sensitivity and has previously been used to distinguish between healthy and pathologic (tender) tissue.[14, 15] Pressure pain thresholds (PPTs) determined by digital algometry are defined as the minimum force applied that induces pain[16] and, as a perceptual response, have been previously used for identifying site-specific differences in pain sensitivity in people with low back pain[17] and neck pain.[18] In addition to their use in detecting peripherally sensitized tissues, PPTs are also

used extensively as part of quantitative sensory testing to estimate central sensitization.[19-21] Central nervous system modulation with generalized hypersensitivity is recognized in many chronic musculoskeletal pain conditions.[22-24] A range of factors in addition to pain can influence tissue sensitivity including age,[25, 26] obesity,[27] mental health[28] and situational stress.[29] With the application of PPTs in quantifying peripheral or central sensitization, these factors have the potential to confound the relationships identified between PPTs and pain.

In this study, digital algometry was used to, 1) investigate if breast size was associated with differences in PPTs across selected musculoskeletal tissues of the upper back, and 2) to evaluate if sensitivity of musculoskeletal tissues is related to self-reported upper back pain. The use of PPTs in this investigation was based on the assumption that local tissue sensitivity may exist in certain musculoskeletal tissues in women with large breasts, and that local tissue sensitivity might explain their experience of upper back pain. It was hypothesized that lower PPTs in musculoskeletal tissues in the upper back would be recorded for women with large breasts compared with women with small breasts, and that this finding would be consistent with reports of more severe upper back pain in these women.

Materials and Methods

This cross-sectional study was part of a large project examining breast size and upper back pain in mature women. The project recruited a community-based sample (n=269) of mature women (≥40 years) via radio, newspaper and online advertising and by word of mouth. Participants completed an online survey upon recruitment which collected a range of self-report data using various standardized measures. A subset of healthy postmenopausal women were selected sequentially by a study supervisor (LM) according to whether or not they had reported upper back pain. A sample with approximately equal number of participants with and without upper back pain was recruited. Upper back pain was defined as pain present for at least one month and located above the base of the ribcage and below the neck. Upper back pain was measured using an 11-point numerical rating scale (0 = no pain, 10 = worst pain imaginable).[30] Volunteers were excluded if they had menstruated within the last 12 months. They were also excluded if they reported: a history of breast or thoracic spine surgery; a systemic inflammatory condition; a neurodegenerative disorder; a known pathology of the breast, lung or thoracic spine; cancer involving the bones; and/or long-term and recent ongoing use of steroid or pain medication. Given this list of exclusion criteria, volunteers with a chronic pain condition or generalized hyperalgesia were likely to have been omitted. All participants provided written informed consent and the study was approved by the Human Research Ethics Committee at Curtin University (Approval number RHDS-267-15).

Participants' general mental health including dimensions of anxiety, depression, and loss of behavioral or emotional control was captured via the mental health subscale of the Medical Outcomes Study Short-Form 36 Health Survey (version 2.0) (SF-36),[31] a generic health-related quality of life measure. A difference in score of 5-points on the mental health subscale was considered clinically meaningful.[32, 33]

Physical measurements of participants were undertaken at a university-based health center on one occasion. All measures were completed by an experienced musculoskeletal physiotherapist (LS) who was blinded to the upper back pain status of participants. Participants were asked to avoid any unaccustomed activity that may induce body soreness in the 48-hours prior to being measured. Room conditions, including temperature and noise, were standardized for all participants.

Measurements of height (m) and weight (kg) were used to calculate body mass index (BMI) (kg/m²). Breast size was measured using under and over-bust circumferences.[34] Under-bust and over-bust circumferences were converted into an ordinal breast size score (BSS) of between 0-18 (see supplemental digital content) using a system employed in prior research.[5, 13]

Measured Characteristics

Pressure pain thresholds (PPTs) at twelve anatomical sites were measured using digital algometry (Fig. 1). These were selected as musculoskeletal sites potentially under strain from increased breast size.[6] Prior to testing, participants stood whilst six skeletal sites (spinous processes of T2, T4, T6, T8 T10, and T12) and six muscular sites (pectoralis major, levator scapulae, sternocleidomastoid, upper trapezius, middle trapezius and lower trapezius) were located by palpation[35, 36] and marked with a non-permanent make-up pen (Fig. 1).

Figure caption content:

Anatomical sites (position of testing):

1. Pectoralis major (supine)
2. Sternocleidomastoid (supine)
3. Levator scapulae (prone)
4. Upper trapezius (prone)
5. Middle trapezius (prone)
6. Lower trapezius (prone)
7. T2 spinous process (prone)
8. T4 spinous process (prone)
9. T6 spinous process (prone)
10. T8 spinous process (prone)
11. T10 spinous process (prone)
12. T12 spinous process (prone)

Figure 1. Anatomical sites for PPT testing

Localization of anatomical sites

Skeletal sites

The spinous process of thoracic vertebrae were identified in sequence in a caudal direction by first locating C7 as the most prominent spinous process[36] and counting down and marking the spinous processes to T2, T4, T6, T8, T10 and T12. The location of T12 was confirmed by palpating the level of the 12th rib. The spinous processes above T12 were then confirmed by counting up from T12.

Muscular sites

As PPTs have been found to be relatively stable within subjects[17, 37-39] all muscular sites were tested in a standardized manner on the non-dominant side only:

- Pectoralis major: 2cm below midpoint of the clavicle

- Levator scapulae: 2cm supero-medially from the superior angle of the scapula

- Sternocleidomastoid: 3cm below the mastoid process

- Upper trapezius: 5cm supero-lateral to the superior angle of the scapula

- Middle trapezius: 2cm lateral to T3 spinous process

- Lower trapezius: 2cm lateral to T8 spinous process

Each anatomical site was tested three times using a circuit protocol where one measurement of PPT was taken at each of the twelve anatomical sites until the circuit was completed.[40] The order of testing was randomly determined prior to testing by selecting numbered cards from a cloth bag. The average of three PPT measures taken at each site was used. Participants were familiarized with equipment prior to testing and were made comfortable in standardized positions for testing at each site (Fig. 1). A 1cm² algometer probe was used to apply a force perpendicular to the skin at each site at a consistent rate of 40kPa/s. A hand-held button connected to the algometer was used by participants to indicate their pain threshold had been reached. Instructions provided to participants were that the button should be pressed as soon as the force of the algometer induced discomfort or pain. Pressure readings (kPa) were taken from the digital display on the algometer and recorded for each site and then concealed to avoid bias of subsequent tests at the same site. To avoid injury, an upper limit cut-off of 1000kPa was imposed. Reliability of the algometry method used in this study was established in a pilot study of 15 separate participants (mean (SD) age 59.0 (13.2)

years) who underwent randomized testing of the twelve anatomical sites over three trials on two separate occasions. Relative estimates of intrarater reliability, calculated using a two-way mixed model with fixed effects ($ICC_{3,K}$) were moderate (ICC >0.70) to excellent (ICC >0.80) across the anatomical sites. An absolute measure of reliability, provided through the calculation of the standard error of the measurement (SEM) (square root of the mean square error term of a repeated measures ANOVA) was also reported for each site and used to indicate expected measurement error.

Statistical Analysis

Descriptive data for participant characteristics and PPT by anatomical site were expressed as mean and standard deviation (SD). PPT data were log-transformed as required to achieve normality for use with parametric tests.

Participants were dichotomized into groups according to their breast size and upper back pain using calculated median scores. Breast sizes were divided into two groups (small (BSS <7) and large (BSS ≥7)) and upper back pain was grouped by severity (nil-mild (NRS <4) and moderate-to-severe (NRS≥4)). Participant characteristics were compared between groups using independent t-tests.

Linear mixed models with random subject effects were used to evaluate differences in PPT between breast size groups (small versus large) and upper back pain groups (nil-mild versus moderate-severe) over twelve anatomical sites (six vertebral and six muscular). Normality of residuals were assessed for model fit. Results were summarized as estimated marginal mean differences and 95% confidence intervals (CIs) and estimated marginal means were displayed graphically. All models were run univariately and adjusted for confounders (age and BMI) if there were significant group differences. Both raw and normalized PPT values were analyzed. Results were reported using raw values for ease of reference. Stata I/C v16.0 (StataCorp LLC, College Station TX) was used for data analysis and significance levels were set at 0.05.

Results

Participant characteristics

One hundred and nineteen postmenopausal women participated in this study. The mean (SD) age, height, weight and BMI of the sample respectively were: 61.4 (7.0) years; 161.4 (6.2) cm and 75.2 (15.2) kg and 28.9 (5.5) kg/m². Across the sample, breast sizes ranged from size 2 to 18 with a mean (SD) BSS of 7.0 (3.2), equivalent to a bra size of 12DD or 14D. Fifty-seven (48%) participants were grouped as having small breasts (mean (SD) BSS: 4.5 (1.3))

and 62 (52%) as having large breasts (mean (SD) BSS: 9.4 (2.5)). Upper back pain severity ranged from 0 to 10 across the sample with the mean (SD) NRS of 4.5 (2.1) in those participants with upper back pain (51%). The nil-mild upper back pain group (mean (SD NRS: 0.5 (1.0)) included 66 (64%) participants. The remaining 43 participants (36%) were categorized as moderate-severe upper back pain (mean (SD) NRS: 5.6 (1.6)).

Between-group differences in participant characteristics

Grouped by breast size, there was no difference in age (MD: -1.2 years, 95% CI: -2.7 to 2.4 years, *p*=0.926) or mental health scores (MD: 4.3, 95%CI: -1.2 to 9.9, *p*=0.126). However, participants with large breasts had a significantly greater BMI than those with small breasts (MD: 7.2kg/m², 95%CI: 8.7 to 5.7kg/m²).

Grouped by upper back pain there was no difference in BMI (MD:-1.1kg/m², 95%CI: -3.1 to 1.0kg/m², *p*=0.664) or mental health scores (MD: 4.0, 95%CI: -1.8 to 9.7, *p*=0.178). However, participants with moderate-severe upper back pain were significantly younger than those with nil-mild upper back pain (MD: 2.8 years, 95% CI: 0.2 to 5.4 years, *p*=0.035).

Pressure pain thresholds

For skeletal sites, PPTs increased caudally from T2 to T10 (Table 1) with mean (SD) PPTs ranging from 365.0kPa (194.2kPa) (T2) to 482.6kPa (201.7kPa) (T10). For muscular tissues, the highest PPTs were recorded for lower trapezius (465.1kPa (182.0kPa) and the lowest PPTs for sternocleidomastoid (114.2kPa (54.9kPa) (Table 1). At skeletal sites, there was wide inter-individual variability in the PPTs as shown by SD values which ranged from 182.6kPa (T6) to 201.7kPa (T10). At muscular sites the greatest variability in PPT was recorded for middle trapezius where a SD value of 206.1kPa was the highest recorded of all sites.

Table 1. Pressure pain thresholds - Between group comparisons

Anatomical site	SEM[a] (kPa)	Mean (SD) (kPa) n=119	Breast size (large (n=62) - small (n=57))		Upper back pain (mod-severe (n=43) - nil-mild (n=76))		Upper back pain (mod-severe (n=43) - nil-mild (n=76)) adjusted for age and BMI	
			MD (95% CI) kPa	*p*-value	MD (95% CI) kPa	*p*-value	MD (95% CI) kPa	*p*-value
Skeletal sites								
T2	69.3	365.0 (194.2)	-5.3 (-72.0 to 61.3)	0.875	-167.7 (-234.3 to -101.1)	<0.001	-144.2 (-210.1 to -78.3)	<0.001
T4	69.3	381.3 (192.8)	10.0 (-56.7 to 76.6)	0.770	-138.0 (-204.6 to -71.4)	0.001	-114.5 (-180.4 to -48.6)	0.001
T6	86.7	408.3 (182.6)	1.4 (-65.2 to 68.1)	0.966	-129.5 (-196.2 to -62.9)	0.002	-106.0 (-172.0 to -40.1)	0.002
T8	71.0	453.5 (197.6)	-3.0 (-69.7 to 63.6)	0.929	-143.5 (-210.1 to -76.8)	<0.001	-120.0 (-185.9 to -54.0)	<0.001
T10	87.3	482.6 (201.7)	49.2 (-17.4 to 115.9)	0.148	-144.8 (-211.4 to -78.1)	<0.001	-121.3 (-187.2 to -55.3)	<0.001
T12	92.9	451.5 (186.6)	49.2 (-17.5 to 115.8)	0.148	-154.0 (-220.6 to -87.3)	<0.001	-130.5 (-196.4 to -64.5)	<0.001
Muscular sites								
Pectoralis major	69.3	363.00 (161.7)	-4.9 (-56.9 to 47.2)	0.855	-87.1 (-140.5 to -33.7)	0.001	-74.6 (-128.0 to -21.1)	0.006
Levator scapulae	25.4	226.7 (117.3)	-10.8 (-62.7 to 41.2)	0.685	-133.4 (-186.8 to -80.1)	<0.001	-120.9 (-174.3 to -67.5)	<0.001
SCM	33.3	114.2 (54.9)	-4.0 (-56.0 to 47.9)	0.879	-32.6 (-85.9 to 20.8)	0.232	-20.0 (-73.4 to 33.4)	0.463
Upper trapezius	80.7	325.4 (158.5)	25.8 (-26.1 to 77.8)	0.330	-108.4 (-161.7 to -55.0)	<0.001	-95.8 (-149.2 to -42.4)	<0.001
Middle trapezius	71.8	446.0 (206.1)	12.7 (-39.2 to 64.7)	0.631	-163.6 (-217.0 to -110.3)	<0.001	-151.1 (-204.5 to -97.7)	<0.001
Lower trapezius	59.9	465.1 (182.0)	10.5 (-41.4 to 62.5)	0.692	-144.3 (-197.6 to -90.9)	<0.001	-131.7 (-185.1 to -78.3)	<0.001

[a] Statistics calculated from pilot work on separate sample (n=15). **Abbreviations:** SEM – standard error of the measurement; MD – mean difference; CI – confidence interval; SCM – sternocleidomastoid; kPa – kilopascals; BMI – body mass index

Pressure pain thresholds and breast size

There were no significant differences in PPTs across all twelve anatomical sites when comparing women with large breasts to women with small breasts (Table 1). The mean differences in PPTs at all sites between breast size groups were small, ranging from 1.4kPa (T6) to 49.2kPa (T11 and T12). In addition, there were no consistent patterns in PPTs when comparing participants according to their breast size (Fig. 2).
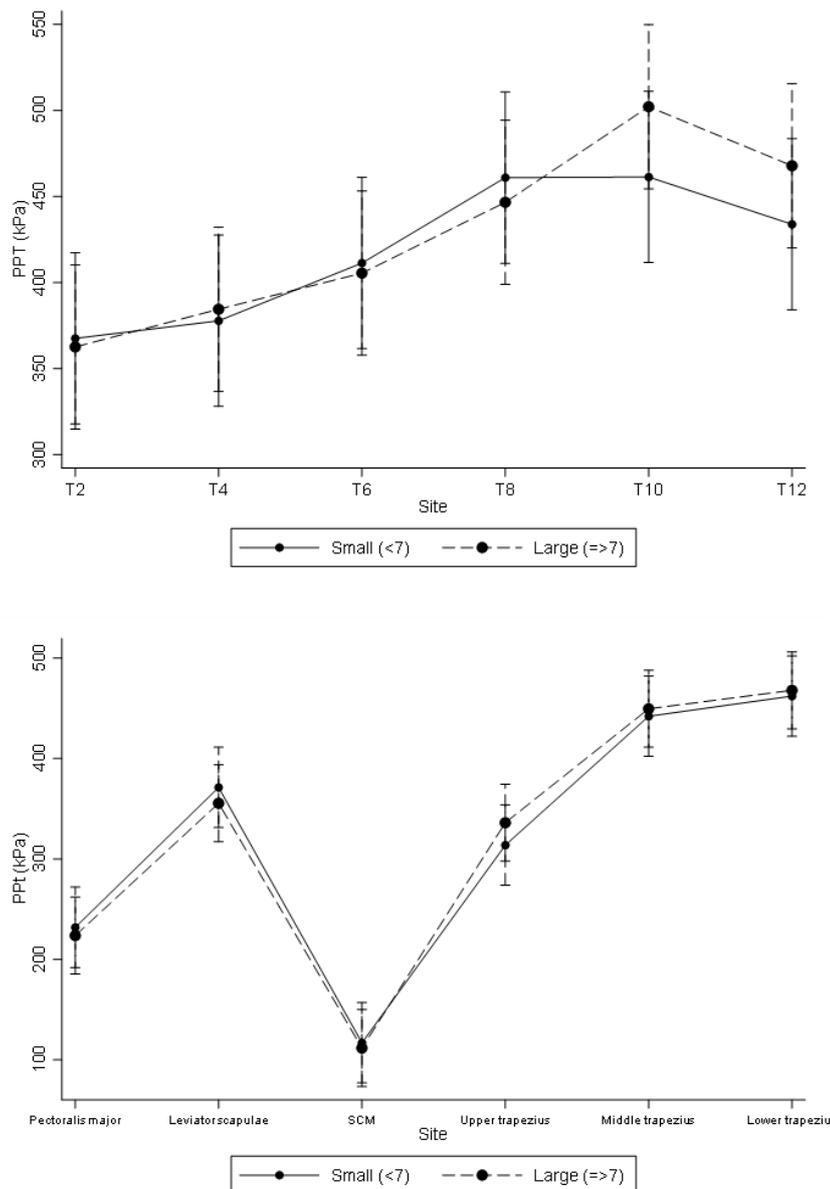
Figure 2. Predicted means and 95% CIs of **a)** skeletal and **b)** muscular tissue PPTs between small and large breast size groups

Abbreviations: PPT – pressure pain threshold, SCM – sternocleidomastoid

Pressure pain thresholds and upper back pain

There were significant differences in PPTs across pain groups at all anatomical sites except for sternocleidomastoid (Table 1 and Fig. 3). Pressure pain thresholds ranged from 87.1kPa (pectoralis major) to 167.7kPa (T2) (Table 1) and were generally lower in participants with moderate-severe upper back pain compared to those with nil-mild upper back pain (Fig. 3). Most between-group differences exceeded the SEM to reflect that these were true differences rather than measurement error (Table 1).
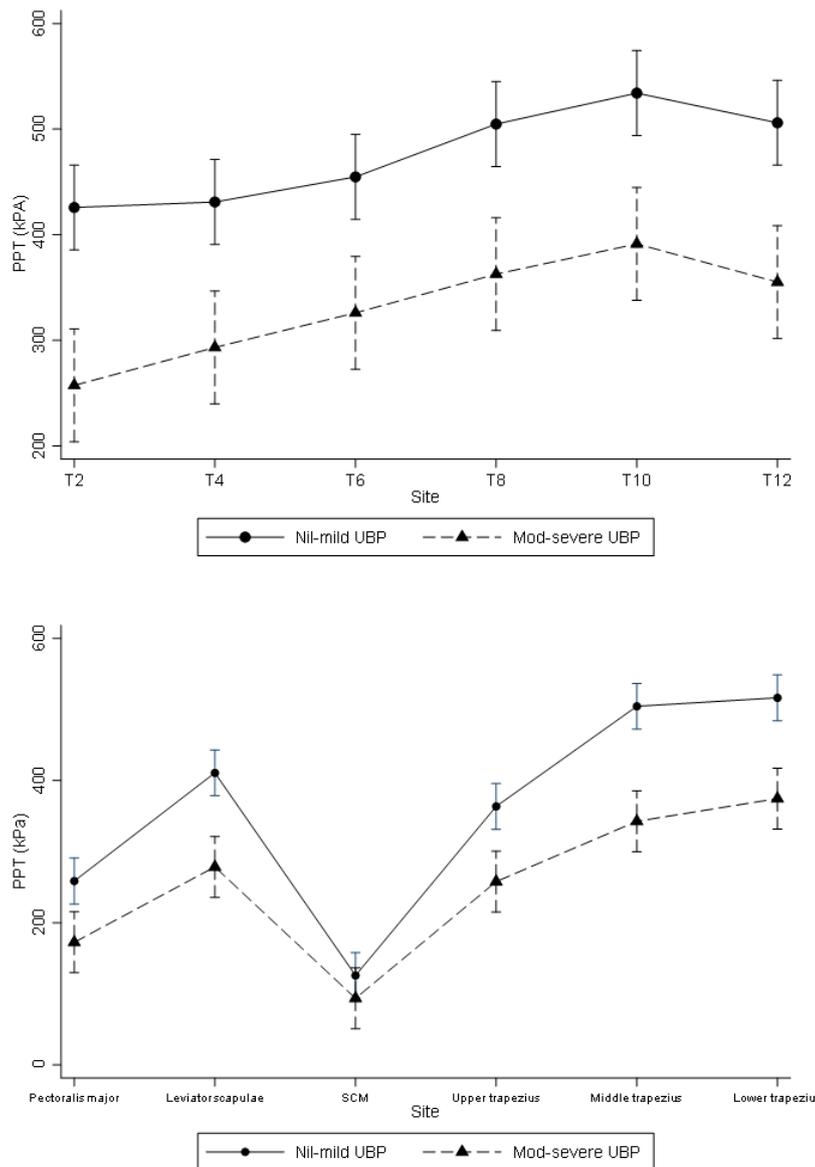
Figure 3. Predicted means and 95% CIs of **a)** skeletal and **b)** muscular tissue PPTs between upper back pain groups

Abbreviations: PPT- pressure pain threshold, SCM – sternocleidomastoid, UBP- upper back pain

Pressure pain thresholds related to breast size and upper back pain

Within upper back pain groups there were no significant differences in PPTs between women with large breasts and those with small breasts (Table 2). This confirmed that once upper back pain had been taken into account, breast size had no significant or meaningful effect on tissue sensitivity at any anatomical site (Fig. 4).

Table 2 Pressure pain thresholds - Between breast size group differences (large minus small) within upper back pain groups

| Anatomical site | SEM[a] (kPa) | Between breast size group differences within upper back pain groups | | | |
| | | nil-mild | | moderate-severe | |
		MD (95% CI) kPa	*p*-value	MD (95% CI) kPa	*p*-value
Skeletal sites					
T2	69.3	8.1 (-71.9 to 88.1)	0.843	-18.8 (-125.4 to 87.8)	0.730
T4	69.3	8.2 (-71.8 to 88.2)	0.841	11.7 (-94.9 to 118.3)	0.829
T6	86.7	-15.5 (-95.5 to 64.5)	0.704	18.4 (-88.2 to 125.0)	0.735
T8	71.0	-33.2 (-113.2 to 46.8)	0.416	27.2 (-79.4 to 133.8)	0.617
T10	87.3	29.5 (-50.5 to 109.5)	0.470	68.9 (-37.6 to 175.5)	0.205
T12	92.9	5.6 (-74.4 to 85.6)	0.892	92.8 (-13.8 to 199.4)	0.088
Muscular sites					
Pectoralis major	69.3	-19.4 (-83.6 to 44.8)	0.554	16.9 (-68.5 to 102.2)	0.698
Levator scapulae	25.4	-31.6 (-95.6 to 32.5)	0.334	19.8 (-65.6 to 105.1)	0.650
SCM	33.3	-11.1 (-75.1 to 53.0)	0.735	6.9 (-78.5 to 92.2)	0.875
Upper trapezius	80.7	-3.0 (-67.1 to 61.0)	0.926	73.3 (-12.1 to 158.6)	0.092
Middle trapezius	71.8	-10.3 (-74.4 to 53.7)	0.752	47.9 (-37.4 to 133.3)	0.271
Lower trapezius	59.9	-22.3 (-86.3 to 41.8)	0.496	63.4 (-22.0 to 148.7)	0.145

[a] Statistics calculated from pilot work on separate sample (n=15). **Abbreviations:** SEM – standard error of the measurement; MD – mean difference; CI – confidence interval; SCM – sternocleidomastoid; kPa – kilopascals; BMI – body mass index
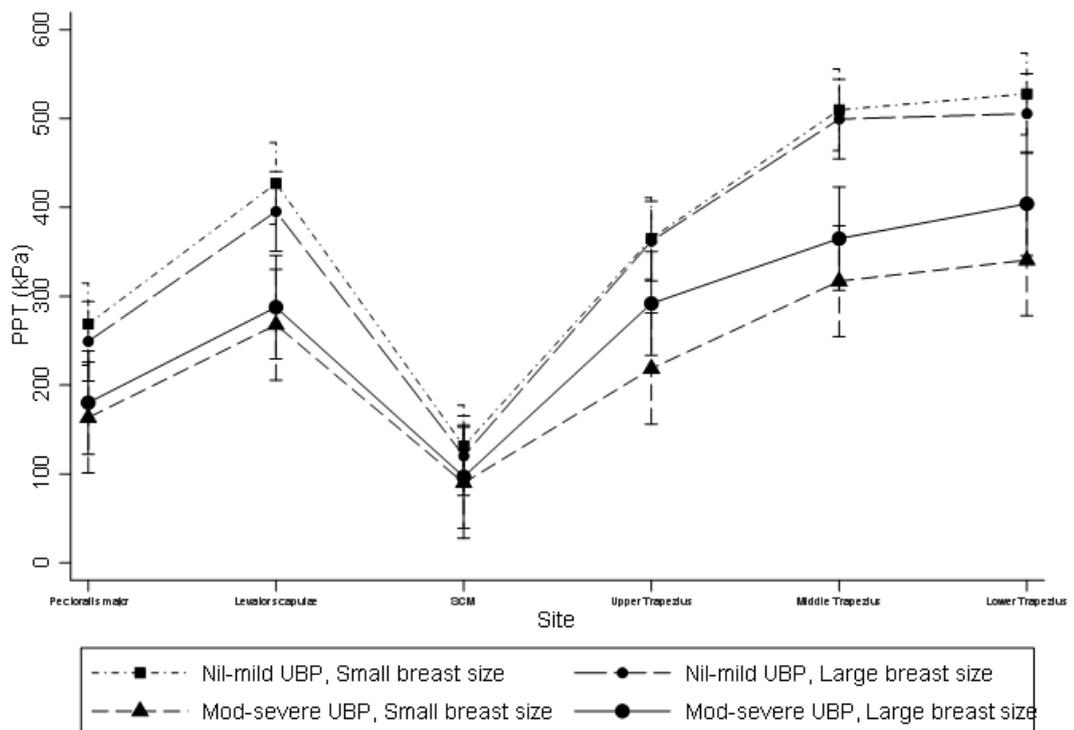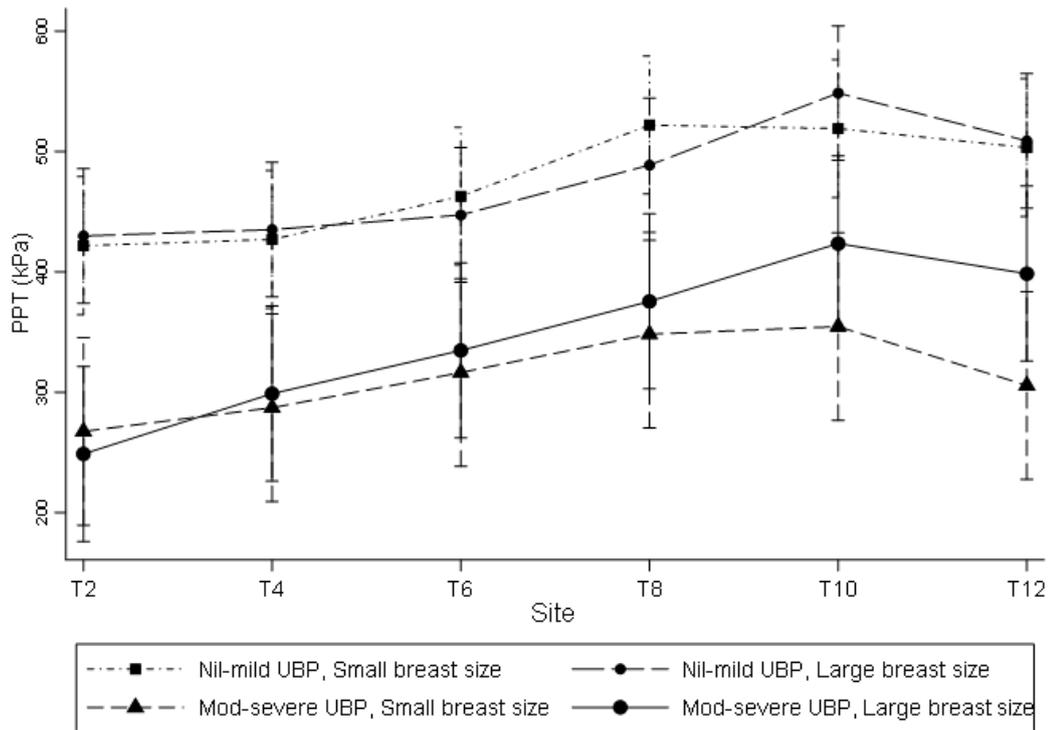
Figure 4. Predicted means and 95% CIs of a) skeletal and b) muscular tissue PPTs according to breast size and upper back pain grouping

Abbreviations: PPT- pressure pain threshold, SCM – sternocleidomastoid, UBP- upper back pain

Discussion

These results confirm that participants with moderate-severe upper back pain are more sensitive across most skeletal and muscular tissues than those with nil-mild upper back pain, regardless of the size of their breasts. Although accumulating evidence points to a structural and mechanical cause for upper back experienced by women with large breasts,[2, 10-13] it remains speculative that skeletal and muscular tissues in the upper back become strained, sensitized and symptomatic as a result.

The anatomical basis for upper back pain in women with large breasts is considerably understudied despite it being reported as a common complaint in this population.[1-5] By quantifying PPTs in a large sample of women, our study is the first to report on the sensitivity of upper back musculoskeletal tissues in women of different breast sizes. The role of breast size in increasing the sensitivity of these upper back tissues was not supported in our study. Lower PPTs in the women with large breasts who also had more severe upper back pain are perhaps suggestive of a relationship between the strain on upper back tissue and upper back pain. However, greater sensitivity in most of the tissues examined in this study was related only to higher severities of upper back pain. Consequently, the current study provides no theoretical support that upper back pain in women with large breasts is a musculoskeletal disorder with a likely biomechanical cause. This means that the putative role of breast size in increasing the strain on tissues is also unsupported.

An assumption prior to conducting this study was that strained tissues in women with large breasts would be more sensitive and this was expected to align with self-reported upper back pain. The clinical utility of PPTs in identifying strained and symptomatic tissues has been previously demonstrated in studies of delayed onset muscle soreness where lower PPTs have been recorded for muscles made sore through experimental over-use.[41, 42] Tenderness in tissues is also widely used in clinical practice as a symptom of musculoskeletal strain, injury or damage. The discriminatory power of PPTs and their validity in identifying tender tissues relevant to musculoskeletal pain conditions has been reported for low back pain,[17] knee osteoarthritis[43] and neck pain.[44] Although breast size in this instance has been shown to be seemingly unimportant in contributing to upper back tissue sensitivity, our results have nevertheless allowed us to locate sensitized tissues that could be relevant to self-reported upper back pain.

Statistically significant differences in PPTs between our two pain groups were noted at 11 of the 12 anatomical sites we examined. We think it is unlikely that these differences were related to central causes (central sensitization) since our sample comprised healthy

172

volunteers who reported no long-term or ongoing use of pain medication. We also noted the comparable mental health scores between pain groups which indicated that psychological factors were unlikely influences on sensitivity responses in our participants. Whilst the differences in PPTs between the two pain groups at 11 sites reached statistical significance, the clinical meaningfulness of these differences need to be considered. A meaningful difference in PPT has been reported to be between 1.5-2.0kg/cm² (147-196kPa).[16] Without adjusting for participants' age or BMI, differences of this magnitude were only recorded in our study at three anatomical sites (T2, T12 and middle trapezius) suggesting that these particular sites may be most clinically relevant in people with upper back pain. Whilst we cannot be sure how PPTs relate to upper back pain, there could be plausible local physiological reasons why T2 and T12, the top and bottom of the thoracic curve, and middle trapezius, a prominent postural back muscle, recorded the most noticeable and meaningful differences in PPTs between our two pain groups. Unfortunately, we cannot be sure if there is a causal link between pain sensitivity at these sites and the severity of upper back pain, or indeed whether upper back pain is a condition that drives sensitivity at these sites.

After adjustment for age and BMI, the only site showing a clinically meaningful difference in PPT between the pain groups was middle trapezius. The PPTs recorded for middle trapezius amongst participants with moderate-severe upper back pain were not only meaningfully lower than those recorded for participants with nil-mild upper back pain, but were also far lower than the normalized values previously reported for a young healthy pain-free sample.[45] Our findings suggest that the sensitivity of middle trapezius could be a useful objective marker for upper back pain and could be used as such in future studies.

It was of interest that the sensitivity of sternocleidomastoid was the only site where no significant difference in PPT was found between the two pain groups. This could indicate that this muscle is not substantially involved in upper back pain. In comparison to previously published PPT data, the average thresholds acquired for sternocleidomastoid in our sample were notably lower with mean (SD) values of 114kPa (54.9kPa) compared with thresholds in asymptomatic populations of comparable age of between 185kPa[25] and 383kPa.[46] Values as low as 193kPa have been reported in women with chronic migraine (mean (SD) age 38 (10.42) years).[47] Sternocleidomastoid was the most sensitive of all the anatomical sites tested in our study and this appeared to be the case for all participants regardless of their breast size or upper back pain status. As a muscle with a small cross-sectional area that is located near the neural tissue of the brachial plexus, it is perhaps unsurprising that this was the most sensitive test site.

In this study, new knowledge about upper back pain and upper back tissue sensitivity is presented. However, it is important to explore why breast size appeared to have no clear association with increased upper back tissue sensitivity, because the results raise questions over existing theories on the nature and cause of upper back pain in women with large breasts.[6] Competing explanations for our findings include that we may have been unable to detect differences in tissue sensitivity because of the range of breast sizes included. Changes in upper back tissue sensitivity may only be seen in women with very large breasts, larger than our 'large' breast group. If changes in spinal alignment and posture drive the potential for heightened musculoskeletal sensitivity, then it is important to acknowledge that relationships between breast size and spine or body posture have only been consistently observed in small studies of women with macromastia (excessively large breasts) awaiting reduction mammoplasty.[7-9] It is therefore possible that in our sample, there were insufficient numbers of women with very large breasts and this may have limited us in identifying differences in tissue sensitivity between our breast size groups. Another consideration is whether upper back pain and/or tissue sensitivity could be transient features in women with large breasts, perhaps changing with time, physical activity or even body position. By measuring musculoskeletal tissues of participants in a gravity-eliminated position it is possible that we did not elicit the same strain on tissues that are hypothesized in upright positions.[6] Symptom duration is another factor likely to be associated with manifestations of increased tissue sensitivity. From our data it is not clear how long participants with upper back pain had been experiencing their severity of upper back pain. Consequently, having a mix of subacute and chronic pain presentations may have interfered with our capacity to identify trends in tissue sensitivity between the two breast size groups. It has been speculated for example, that strain to musculoskeletal tissues in women with large breasts may be an accumulative process, developing over many years.[2,4] With this in mind we might only expect to capture greater sensitivity in the musculoskeletal tissues of women who have had large breasts most of their life and experienced upper back pain for some time. Finally, we used PPTs in this study as the only marker of tissue strain and assumed that this would be adequate for its intended purpose. The addition of other clinical measures, such as muscle length and strength tests, may have provided a different picture of the relationship between breast size and upper back tissue strain.

There are also a number of factors related to the measurement of PPTs and that should be considered in the context of the current findings as sources of tissue sensitivity variability. There was wide variability in PPTs across participants both within and between tissues that we tested. Heterogeneity of PPTs at the same site is a consistent finding in prior research.[28, 48-50] It is an aspect of digital algometry that makes it difficult to identify and make sense of trends

in PPT data between different body sites. The mechanical properties of different tissues are also a source of influence when measuring PPTs.[51, 52] Some of the muscular sites tested in our study were located close to musculotendinous areas whereas others were in the mid-belly of the muscle. These are reported to have differences in pressure-pain tolerance.[45] Algometer probe shape, positioning, pressure rate and pressure application angle relative to the shape and cross-sectional area of the tissue being measured are also factors that may lead to unwanted variation in PPTs.[49, 51, 53, 54] Establishing the reliability of the tester in measuring PPTs and the SEMs at each of the anatomical sites was a strength of this study providing us with confidence that these factors were not a substantial influence.

In summary, breast size was not found to be associated with differences in upper back tissue sensitivity using digital algometry in postmenopausal women. Consequently, the findings do not support the theory that larger breast sizes are related to greater strain of upper back musculoskeletal tissues. It therefore remains unclear if and how structural or mechanical factors related to breast size contribute to upper back pain in women with large breasts. An additional finding of this study was that lower PPTs measured at the middle trapezius look to be a key feature of women experiencing moderate-severe upper back pain, irrespective of their breast size. Middle trapezius is recognized from our study as the only site within the upper back that clearly and meaningfully distinguishes women with moderate-severe upper back pain from those with nil-mild upper back pain.

We acknowledge the limitations of our study which include that our measure of breast size is only one of several that are available and using another method may have yielded different results. In addition, like many other non-surgical measures of breast size, we cannot be certain of how precise our estimates of breast size were. We used PPTs as a measure of tissue sensitivity to estimate musculoskeletal strain and whilst we attempted to control as many confounding factors as was practicable, we recognize that there could be other potential influences affecting tissue sensitivity that we did not consider or quantify.

Future studies might recruit women with very large breast sizes and/or a greater range of breast sizes and upper back pain severities to corroborate our results. Important additions to any further studies of breast size in relation to PPTs are to employ more specific exclusion criteria to eliminate volunteers with chronic pain showing possible hyperalgesia and/or to explore sensitivity at a remote body site, unrelated to the upper back, to more definitively identify a participant with a underlying hypersensitivity disorder.

Conclusion

By examining the PPTs in musculoskeletal tissues of the upper back we conclude that upper back pain severity is related to increased tissue sensitivity but breast size is not. Middle trapezius may be a site of interest for researchers and clinicians targeting treatments at improving upper back pain.

References

1. Greenbaum AR, Heslop T, Morris J, et al. An investigation of the suitability of bra fit in women referred for reduction mammaplasty. *Brit J Plast Surg.* 2003; 56: 230-236.

2. McGhee D, Coltman KA, Riddiford-Harland DL, et al. Upper torso pain and musculoskeletal structure and function in women with and without large breasts: A cross sectional study. *Clin Biomech.* 2018; 51: 99-104.

3. Coltman CE, Steele JR and McGhee DE. Can breast characteristics predict upper torso musculoskeletal pain? *Clin biomech.* 2018; 53: 46-53. 2018/02/16.

4. Spencer L and Briffa K. Breast size, thoracic kyphosis & thoracic spine pain - association & relevance of bra fitting in post-menopausal women: a correlational study. *Chiropr ManTher.* 2013; 21: 1-8.

5. Spencer L, McKenna L, Fary R, et al. Upper back pain in postmenopausal women and associated physical characteristics. *PLoS One.* 2019; 14: e0220452.

6. Letterman GS, M. The effects of mammary hypertrophy on the skeletal system. *Ann Plast Surg.* 1980; 5: 425-431.

7. Berberoğlu Ö, Temel M and Türkmen A. Effects of Reduction Mammaplasty Operations on the Spinal Column: Clinical and Radiological Response. *Aesthet Plast Surg.* 2015; 39: 514-522.

8. Findikcioglu K, Findikcioglu F, Ozmen S, et al. The impact of breast size on the vertebral column: A radiologic study. *Aesthet Plast Surg.* 2007; 31: 23-27.

9. Karabekmez FE, Gokkaya A, Isik C, et al. Does reduction mammaplasty revert skeletal disturbances in the vertebral column of patients with macromastia? A preliminary study. *Aesthet Plast Surg.* 2014; 38: 104-112.

10. Coltman CE, Steele JR and McGhee DE. Effect of Breast Size on Upper Torso Musculoskeletal Structure and Function: A Cross-Sectional Study. *Plast Reconstr Surg.* 2019; 143: 686-695.

11. Hansraj KK. Breast Forces on the Spine. *Surg Technol Int.* 2016; 28: 311-315.

12. Benditte-Klepetko H, Leisser V, Paternostro-Sluga T, et al. Hypertrophy of the breast: a problem of beauty or health? *J Women's Health.* 2007; 16: 1062-1069.

13. Spencer L, McKenna L, Fary R, et al. Is breast size related to prevalent thoracic vertebral fracture? A cross-sectional study. *JBMR Plus.* 2020; e10371.

14. Vanderweeen L, Oostendorp RA, Vaes P, et al. Pressure algometry in manual therapy. *Man Ther.* 1996; 1: 258-265.

15. Suokas AK, Walsh DA, McWilliams DF, et al. Quantitative sensory testing in painful osteoarthritis: a systematic review and meta-analysis. *Osteoarthr Cartil.* 2012; 20: 1075-1085.

16. Fischer AA. Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. *Pain.* 1987; 30: 115-126.

17. Farasyn A and Meeusen R. The influence of non-specific low back pain on pressure pain thresholds and disability. *Eur J Pain.* 2005; 9: 375-381.

18. Pacheco J, Raimundo J, Santos F, et al. Forward head posture is associated with pressure pain threshold and neck pain duration in university students with subclinical neck pain. *Somatosens Mot Res.* 2018; 35: 103-108.

19. Uddin Z and MacDermid JC. Quantitative Sensory Testing in Chronic Musculoskeletal Pain. *Pain Med.* 2016; 17: 1694-1703.

20. Pavlaković G and Petzke F. The role of quantitative sensory testing in the evaluation of musculoskeletal pain conditions. *Curr Rheumatol Rep.* 2010; 12: 455-461.

21. Starkweather A, Heineman A, Storey S, et al. Methods to Measure Peripheral and Central Pain Sensitization Using Quantitative Sensory Testing: A Focus on Individuals with Low Back Pain. *Appl Nurs Res.* 2015; 29: 237-41.

22. O'Sullivan P, Waller R, Wright A, et al. Sensory characteristics of chronic non-specific low back pain: a subgroup investigation. *Man Ther.* 2014; 19: 311-318.

23. Sterling M, Jull G, Vicenzino B, et al. Sensory hypersensitivity occurs soon after whiplash injury and is associated with poor recovery. *Pain.* 2003; 104: 509-517.

24. O'Neill S, Manniche C, Graven-Nielsen T, et al. Generalized deep-tissue hyperalgesia in patients with chronic low-back pain. *Eur J Pain.* 2007; 11: 415-420.

25. Marini I, Bortolotti F, Bartolucci ML, et al. Aging effect on pressure pain thresholds of head and neck muscles. *Aging clin Exp Res.* 2012; 24: 239-244.

26. Magerl W, Krumova EK, Baron R, et al. Reference data for quantitative sensory testing (QST): refined stratification for age and a novel method for statistical comparison of group data. *Pain.* 2010; 151: 598-605.

27. Tashani OA, Astita R, Sharp D, et al. Body mass index and distribution of body fat can influence sensory detection and pain sensitivity. *Eur J Pain.* 2017; 21: 1186-1196.

28. Waller R, Smith AJ, O'Sullivan PB, et al. Pressure and cold pain threshold reference values in a large, young adult, pain-free population. *Scand J Pain.* 2016; 13: 114-122.

29. Hven L, Frost P and Bonde JP. Evaluation of Pressure Pain Threshold as a Measure of Perceived Stress and High Job Strain. *PLoS One.* 2017; 12: e0167257.

30. Boonstra AM, Stewart RE, Köke AJA, et al. Cut-Off Points for Mild, Moderate, and Severe Pain on the Numeric Rating Scale for Pain in Patients with Chronic Musculoskeletal Pain: Variability and Influence of Sex and Catastrophizing. *Front Psychol.* 2016; 7: 1466-1466.

31. Ware JE, Kosinski M and Dewey JE. *How to Score Version 2 of the SF-36 Health Survey.* Lincoln, RI: QualityMetric Incorporated, 2000.

32. Samsa G, Edelman D, Rothman ML, et al. Determining Clinically Important Differences in Health Status Measures: A General Approach with Illustration to the Health Utilities Index Mark II. *PharmacoEconomics.* 1999; 15: 141-155.

33. Hays RD and Woolley JM. The concept of clinically meaningful difference in health-related quality-of-life research. How meaningful is it? *PharmacoEconomics.* 2000; 18: 419-423.

34. Zheng R, Yu W and Fan J. 2 - Breast measurement and sizing. In: Yu W, Fan J, Harlock SC, et al. (eds) *Innovation and Technology of Women's Intimate Apparel*. Cambridge: Woodhead Publishing, 2006, pp.28-58.

35. Stone R and Stone J. *Atals of skeletal muscles*. 4th edition ed. London: McGraw-Hill 2003.

36. Neumann DA. *Kinesiology of the musculoskeletal system : foundations for rehabilitation*. St. Louis, Mo.: Mosby/Elsevier, 2010.

37. Prushansky T, Handelzalts S and Pevzner E. Reproducibility of pressure pain threshold and visual analog scale findings in chronic whiplash patients. *Clin J Pain.* 2007; 23: 339-345.

38. Park G, Kim CW, Park SB, et al. Reliability and usefulness of the pressure pain threshold measurement in patients with myofascial pain. *Ann Rehabil Med.* 2011; 35: 412-417.

39. Brennum J, Kjeldsen M, Jensen K, et al. Measurements of human pressure-pain thresholds on fingers and toes. *Pain.* 1989; 38: 211-217.

40. Bisset LM, Evans K and Tuttle N. Reliability of 2 Protocols for Assessing Pressure Pain Threshold in Healthy Young Adults. *J Manipulative Physiol Ther*. 2015; 38: 282-287.

41. Fleckenstein J, Simon P, Konig M, et al. The pain threshold of high-threshold mechanosensitive receptors subsequent to maximal eccentric exercise is a potential marker in the prediction of DOMS associated impairment. *PLoS One.* 2017; 12: e0185463.

42. Nie H, Kawczynski A, Madeleine P, et al. Delayed onset muscle soreness in neck/shoulder muscles. *Eur J Pain.* 2005; 9: 653-653.

43. Suokas AK, Walsh DA, McWilliams DF, et al. Quantitative sensory testing in painful osteoarthritis: a systematic review and meta-analysis. *Osteoarthr Cartil.* 2012; 20: 1075-1085.

44. Walton DM, Macdermid JC, Nielson W, et al. A descriptive study of pressure pain threshold at 2 standardized sites in people with acute or subacute neck pain. *J Orthop Sports Phys Ther.* 2011; 41: 651-657.

45. Binderup AT, Arendt-Nielsen L and Madeleine P. Pressure pain sensitivity maps of the neck-shoulder and the low back regions in men and women. *BMC Musculoskelet Disord.* 2010; 11: 234.

46. Antonaci F, Sand T and Lucas GA. Pressure algometry in healthy subjects: inter-examiner variability. *Scand J rehabil Med.* 1998; 30: 3-8.

47. Grossi DB, Chaves TC, Goncalves MC, et al. Pressure pain threshold in the craniocervical muscles of women with episodic and chronic migraine: a controlled study. *Arq neuropsiquiatr.* 2011; 69: 607-612.

48. Ylinen J, Nykanen M, Kautiainen H, et al. Evaluation of repeatability of pressure algometry on the neck muscles for clinical use. *Man Ther.* 2007; 12: 192-197.

49. Melia M, Geissler B, Konig J, et al. Pressure pain thresholds: Subject factors and the meaning of peak pressures. *Eur J Pain.* 2019; 23: 167-182.

50. Chesterton LS, Sim J, Wright CC, et al. Interrater reliability of algometry in measuring pressure pain thresholds in healthy humans, using multiple raters. *Clin J Pain.* 2007; 23: 760-766.

51. Finocchietti S, Nielsen M, Morch CD, et al. Pressure-induced muscle pain and tissue biomechanics: a computational and experimental study. *Eur J Pain.* 2011; 15: 36-44.

52. Finocchietti S, Morch CD, Arendt-Nielsen L, et al. Effects of adipose thickness and muscle hardness on pressure pain sensitivity. *Clin J Pain.* 2011; 27: 414-424.

53. Linde LD, Kumbhare DA, Joshi M, et al. The Relationship between Rate of Algometer Application and Pain Pressure Threshold in the Assessment of Myofascial Trigger Point Sensitivity. *Pain Pract.* 2018; 18: 224-229.

54. Finocchietti S, Andresen T, Arendt-Nielsen L, et al. Pain evoked by pressure stimulation on the tibia bone - influence of probe diameter on tissue stress and strain. *Eur J Pain.* 2012; 16: 534-542.

55. Berlei. Australian Bra Sizes. Available at: https://www.berlei.com.au/size-charts. Accessed January 201

Supplemental Digital Content

	Cup Size	Band size (under-bust circumference, cm)									
		8 (63-67)	10 (68-72)	12 (73-77)	14 (78-82)	16 (83-87)	18 (88-92)	20 (93-97)	22 (98-102)	24 (103-107)	26 (108-112)
Breast size score (over-bust circumference, cm)	AA	0 (75-77)	1 (80-82)	2 (85-87)	3 (90-92)	4 (95-97)	5 (100-102)	6 (105-107)	7 (110-112)	8 (115-117)	9 (120-122)
	A	1 (77-79)	2 (82-84)	3 (87-89)	4 (92-94)	5 (97-99)	6 (102-104)	7 (107-109)	8 (112-114)	9 (117-119)	10 (122-124)
	B	2 (79-81)	3 (84-86)	4 (89-91)	5 (94-96)	6 (99-101)	7 (104-106)	8 (109-111)	9 (114-116)	10 (119-121)	11 (124-126)
	C	3 (81-83)	4 (86-88)	5 (91-93)	6 (96-98)	7 (101-103)	8 (106-108)	9 (111-113)	10 (116-118)	11 (121-123)	12 (126-128)
	D	4 (83-85)	5 (88-90)	6 (93-95)	7 (98-100)	8 (103-105)	9 (108-110)	10 (113-115)	11 (118-120)	12 (123-125)	13 (128-130)
	DD	5 (85-87)	6 (90-92)	7 (95-97)	8 (100-102)	9 (105-107)	10 (110-112)	11 (115-117)	12 (120-122)	13 (125-127)	14 (130-132)
	E	6 87-89)	7 (92-94)	8 (97-99)	9 (102-104)	10 (107-109)	11 (112-114)	12 (117-119)	13 (122-124)	14 (127-129)	15 (132-134)
	F	7 (89-91)	8 (94-96)	9 (99-101)	10 (104-106)	11 (109-111)	12 (114-116)	13 (119-121)	14 (124-126)	15 (129-131)	16 (134-136)
	G	8 (91-93)	9 (96-98)	10 (101-103)	11 (106-108)	12 (111-113)	13 (116-118)	14 (121-123)	15 (126-128)	16 (131-133)	17 (136-138)
	H	9 (93-95)	10 (98-100)	11 (103-105)	12 (108-110)	13 (113-115)	14 (118-120)	15 (123-125)	16 (128-130)	17 (133-135)	18 (138-140)

Breast size score conversion chart. To determine a breast size score first identify the correct bra size (band and cup size). Establish the correct band size by measuring around the body, directly below the bust (under-bust circumference) and the correct cup size by measuring across the fullest part of the breasts whilst wearing a bra (over-bust circumference)[55]. Use the top row of the table to select the band size, this increases from left to right. Then use the first column of the table to select the cup size, this increases from top to bottom. Track down and across to find the table cell where these two selections intersect. Breast size score is shown in bolded text.

Attribution Statement							
Co-authored publication	**Conception, design and methodology**	**Implementation of methodology and acquisition of data**	**Data analysis**	**Interpretation and discussion**	**Writing of original draft**	**Review and editing**	**Final approval**
Chapter 11. Taking the strain: An examination of upper back musculoskeletal tissue sensitivity in relation to breast size and upper back pain.							
Thesis Candidate: Linda Spencer	✓	✓	✓	✓	✓	✓	✓
Thesis Candidate Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 1: Dr Robyn Fary	✓					✓	✓
Co Author 1 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 2: Dr Leanda McKenna	✓	✓				✓	✓
Co Author 2 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 3: Ms Angela Jacques			✓	✓		✓	✓
Co Author 3 Acknowledgment: I acknowledge that these represent my contribution to the above research output							
Co-author 4: Dr Kathy Briffa	✓		✓	✓		✓	✓
Co Author 4 Acknowledgment: I acknowledge that these represent my contribution to the above research output							

Chapter 12 Reduction mammoplasty: time-series analysis of changes in self-report and physical characteristics

12.1 Abstract

Objectives: The aim of this chapter was to examine the nature, rate and clinical relevance of improvements in self-reported aspects of health and psychological wellbeing and physical characteristics following reduction mammoplasty to help clarify our understanding of upper back pain (UBP) in this population.

Methods: In a repeated measures study, women undergoing reduction mammoplasty were assessed prior to surgery and at 3, 6 and 12-months post-surgery. Self-report characteristics that were measured included: breast and bra fit perceptions (BREAST-Q and participant information questionnaire), UBP presence (yes/no), UBP severity (Numerical Rating Scale (NRS)), neck pain disability (Neck Disability Index (NDI)), shoulder pain (NRS), pain chronicity (Orebro Musculoskeletal Pain Screening Questionnaire (OMPSQ)), physical activity levels (Human Activity Profile (HAP)), health-related quality of life (HRQoL) (Medical Outcomes Study Short Form 36 Health Survey (SF-36) and BREAST-Q), body satisfaction (NRS), and satisfaction with surgery-outcomes (BREAST-Q). Physical characteristics that were measured included: height, weight, bone mineral density (Dual-energy X-ray absorptiometry (DXA)), body composition (DXA), breast size (breast size score (BSS)), breast characteristics (tape measure), upper back extensor muscle endurance (isometric chest raise test), upper back mobility (photogrammetry), thoracic kyphosis (X-ray) vertebral fractures (X-ray), thoracic osteoarthritis (X-ray), posture (photogrammetry), and upper back musculoskeletal tissue sensitivity (digital algometry). Pre-to-post changes were determined using repeated measures analysis of variance or non-parametric equivalents.

Results: Eleven women (mean (SD) age 57.3 (9.4) years) participated. Average total resected breast weight per participant was 964.9g (SD: 393.9g). Self-report characteristics that changed following surgery included: UBP severity (Effect size (ES): 0.16, $p<0.001$), neck pain disability (ES: 0.42, $p<0.001$), shoulder pain severity (ES: 0.30, $p<0.001$), SF-36 physical component summary (PCS) scores (ES: 0.21, $p=0.007$), breast-related psychosocial wellbeing (ES: 0.54, $p<0.001$), and breast-related physical wellbeing (ES: 0.52, $p<0.001$). Breast satisfaction showed a 214% improvement (ES: 0.57, $p<0.001$) by 6-months post-surgery and this improvement was strongly correlated ($r=0.72$) with satisfaction with the outcome of surgery. Physical characteristics, other than breast size that changed included:

head posture (ES: 0.25, p=0.010) and the sensitivity of levator scapulae (p=0.007)) and lower trapezius (p=0.002). Upper back extensor muscle endurance improved to a clinically-relevant level but the change was not statistically significant.

Conclusion: In this small sample, the improvements conferred by reduction mammoplasty appear to be mostly in self-report characteristics up to 12-months post-surgery. Self-reported aspects of health and psychological wellbeing improved quicker, and by greater amounts, than objectively-measured physical characteristics that were assumed to be related to breast size. Upper back pain is relieved early in the postoperative period and this is independent of breast resection weight.

12.2 Introduction

Reduction mammoplasty is a surgical procedure involving resection of breast tissue by a predetermined amount that is most commonly used to reduce the self-reported and physical burden of large breasts. Common complaints related to breast size include low HRQoL, low body satisfaction, and physical activity limitations[25, 43, 75]. Other symptoms reported by women preoperatively include upper back and neck pain, long-standing rashes under the breasts, and discomfort from bra shoulder straps[25, 26, 41]. Although the burden related to large breasts has been illustrated in women presenting for reduction mammoplasty, the procedure is still largely considered a cosmetic procedure and not a medical necessity[283, 284]. Contributing to this is the uncertainty surrounding how reduction mammoplasty alleviates symptoms and physical burden associated with large breasts.

The self-reported benefits identified by women following reduction mammoplasty include improvement in back pain[25, 26, 40, 41, 48, 69, 70], HRQoL[46, 71-74], breast satisfaction[46, 73, 76], body image[75], depression and anxiety[40, 77]. The positive changes seen in these characteristics have been reported to occur as early as one-month following surgery[73], suggesting that there may be an immediate emotional response to the procedure that may account for the changes observed. There is also evidence showing the longevity of the improvements, with HRQoL, for example, being improved and maintained up to 5-years post-surgery[79]. Importantly, there are rarely reports of women being subjectively worse after undergoing reduction mammoplasty. Although temporary postoperative complications affect between 10%[25] and 43%[285] of women, it is uncommon for these to require surgical revision or to negatively affect the overall positive outcome from surgery[42, 80, 286]. In addition, the benefits conferred by reduction mammoplasty are consistently seen to be independent of resected breast weight[25, 26, 41, 42, 46, 73]. Whilst this illustrates that the procedure is valuable to women undergoing both large and small reductions, it does little to explain a physical basis for the improvements that are seen.

Physical characteristics showing change following reduction mammoplasty are less widely investigated but have been reported to include an improvement in cervical lordosis and thoracic kyphosis angles[40, 50, 51]. Additionally, pelvic posture[48, 67] and the position of the body's centre of mass[66] normalise postoperatively. Putative biomechanical mechanisms may explain these physical changes where the body's alignment responds to the alleviation of downward drag of heavy breasts on the anterior chest[27]. How these physical changes relate to self-report complaints is not certain.

To date, self-report and physical changes associated with reduction mammoplasty have not been extensively examined together. Whether the changes in these characteristics are related or are independent of each other is unknown. The comparative rate at which changes occur has also not been considered, but could provide insight into the mechanisms that underpin the benefits of reduction mammoplasty. Furthermore, the multidimensional nature of symptoms, varied reasons for undergoing the procedure, and differences in outcome expectations between women make reduction mammoplasty success a difficult entity to define, measure and therefore predict[26].

The purpose of this chapter was therefore to collectively examine the self-report and physical characteristics that change following reduction mammoplasty with the purpose of identifying the nature, rate and clinical relevance of improvements that occur.

12.3 Methods

Adult women (aged ≥18 years-old) seeking reduction mammoplasty were recruited for this study using the methods outlined in Chapter 2, section 2.2.3. Volunteers were subject to the general exclusion criteria detailed in section 2.2.4 and specific exclusion criteria are detailed in section 2.2.5.

Participants underwent repeated assessment of self-report and physical characteristics (Table 12.1) using methods outlined in Chapter 2. Assessments occurred pre-surgery (no more than a month prior to surgery) and at 3, 6 and 12-months post-surgery. Participants disclosed their reasons for undergoing reduction mammoplasty in response to a question in the preoperative participant information questionnaire (Appendix 4a).

Table 12.1 Summary of measured characteristics

Characteristics	Pre-surgery	Post-surgery 3-months	6-months	12-months
Self-report				
Participant characteristics				
Age (yrs)	•	•	•	•
Menopausal status (pre/peri/post)	•	•	•	•
Employment status (FT/PT/nil)	•	•	•	•
Breast and bra fit perceptions				
Breast satisfaction (BREAST-Q)	•	•	•	•
Bra fit satisfaction (yes/no)	•	•	•	•
Breast embarrassment (yes/no)	•	•	•	•
Bra fit satisfaction (yes/no)	•	•	•	•
Desire to change breasts (yes/no)	•	•	•	•
Pain Characteristics				
UBP Presence (yes/no)	•	•	•	•
UBP Severity (NRS)	•	•	•	•
Neck pain disability (NDI)	•	•	•	•
Shoulder pain severity (NRS)	•	•	•	•
Pain chronicity (OMPSQ)	•	•	•	•
Physical Activity				
Adjusted activity score (HAP AAS)	•	•	•	•
Health-related quality of life (generic)				
Physical component summary (PCS) score (SF-36)	•	•	•	•
Mental component summary (MCS) score (SF-36)	•	•	•	•
Health-related quality of life (specific)				
Breast-related psychosocial wellbeing (BREAST-Q)	•	•	•	•
Breast-related physical wellbeing (BREAST-Q)	•	•	•	•
Body Satisfaction (NRS)	•	•	•	•
Outcomes of surgery				
Satisfaction with nipples (BREAST-Q)		•	•	•
Satisfaction with outcome (BREAST-Q)		•	•	•
Satisfaction with information (BREAST-Q)		•	•	•
Physical				
Anthropometry				
Height (cm)	•	•	•	•
Weight(kg)	•	•	•	•
Body mass index (kg/m²)	•	•	•	•
Bone mineral density				
BMD average left and right femoral neck (g/cm²)	•		•	•
Body composition				
Lean mass (kg)	•	•	•	•
Fat mass (kg)	•	•	•	•
Breast characteristics				
Breast size (BSS)	•	•	•	•
Breast ptosis (cm)	•	•	•	•
Breast splay (cm)	•	•	•	•
Bra fit (professional criteria: pass/fail)	•	•	•	•
Upper back characteristics				
Upper back extensor muscle endurance (s)	•	•	•	•
Upper back mobility(°)	•	•	•	•
Thoracic kyphosis				
Radiographic Cobb angle (°)[a]	•		•	•
Thoracic spine morphology				
Thoracic vertebral fracture (yes//no)	•		•	•
Thoracic osteoarthritis (nil-mild/ moderate-severe)	•		•	•
Posture				
Head posture (craniovertebral angle) (°)	•	•	•	•
Upper back posture (cervicothoracic angle) (°)	•	•	•	•
Shoulder posture (shoulder protraction angle) (°)	•	•	•	•
Upper back musculoskeletal tissue sensitivity				
Pressure pain thresholds (kPa)	•	•	•	•

[a] Assessment completed off-site. **Abbreviations:** pre - Premenopausal; peri - Peri-menopausal; post - Postmenopausal; FT - Full-time; PT - Part-time; NRS - Numerical Rating Scale; NDI - Neck Disability Index; OMPSQ - Orebro Musculoskeletal Pain Screening Questionnaire; HAP AAS - Human Activity Profile adjusted activity score; SF-36 - Medical Outcomes Study Short-Form 36 Health Survey; PCS - Physical component summary; MCS - Mental component summary; cm – Centimeter; kg- Kilogram; kg/m² – Kilogram per metre-squared; BMD - Bone mineral density; g/cm² - Grams per centimeter-squared; BSS - Breast size score; kPa - Kilopascals.

12.3.1 Self-report measures

The self-report measures used are described in detail in Chapter 2 sections 2.4 and 2.5. In brief, participants indicated their menopausal status in a multiple-choice question (pre, peri or post-menopausal) and whether they were employed (part-time, full-time, nil employment). Bra size was reported in Australian units and included a numerical band and alphabetical cup size. Bra-fit satisfaction (yes/no) was indicated in a closed question. Breast satisfaction was measured using the validated 11-item BREAST-Q instrument that assesses aspects of breast appearance and produces a satisfaction score of between 0 (nil satisfaction) and 100 (completely satisfied)[162] . Score changes 5-10-points (little), 10-20-points (moderate) and >20-points (very much) on the 0-100 scale of the BREAST-Q reflect meaningful changes in breast satisfaction[164]. In two separate questions, participants indicated if they were embarrassed about their breasts (yes/no) and whether they had a desire to change their breasts (yes/no).

The presence of UBP (yes/no) was assessed in a question that referred to pain felt within the upper back region in the previous month. The upper back was defined as above the base of the ribcage and below the neck. An 11-point numerical rating scale (NRS)[151] assessed the severity of UBP between 0 (no pain) and 10 (worst pain imaginable). Scores were interpreted as mild (NRS ≤5), moderate (NRS 6-7) and severe (NRS ≥ 8)[152] and a score change of 2-points indicates a MCIC[155]. The duration of UBP was captured in a multiple-choice question and categorised dichotomously as acute (<3-months) or chronic (≥3-months).

Neck pain and the effect of neck pain on activities of daily living were assessed using the validated NDI[187]. Scores of between 0 (no activity limitation) and 50 (complete activity limitation) were calculated according to developer guidelines and a score change of 5-points indicates a MCIC[287]. Shoulder pain was defined as pain felt in the anterior and posterior aspect of the shoulder joints bilaterally. The severity of shoulder pain was measured using an 11-point NRS of between 0 (no pain) and 10 (worst pain imaginable). A score change of 2-points indicates a MCIC[155]. The OMPSQ measured participant's risk of pain chronicity[195]. The answers to 10 items were used to generate a score of between 1-100 with higher scores denoting greater risk of chronicity and disability. Scores of greater than 50 identify those at greater risk of chronicity[195]. A score change indicating a MCIC is not available for the OMPSQ.

Physical activity was assessed using the validated HAP[169]. Typical daily activity levels were captured in an AAS of between 0-94 where higher scores indicate greater levels of activity. Score changes of 14 points for AAS indicate MCIC[171].

Health-related quality of life was assessed using both a generic and breast-specific measure. The SF-36 was the generic HRQoL tool that was used[133]. The summary scores of the SF-36, the SF-36 PCS and SF-36 MCS are determined from eight subscales of between 0 (worst possible health state) and 100 (best possible health state). A change of at least 5 points (half of a standard deviation) on either summary score indicates a MCIC[178, 179, 288]. The validated BREAST-Q tool was employed to assess breast-specific HRQoL[134] via two subscales - physical wellbeing (14-items) and psychosocial wellbeing (9-items). These subscales measure the physical problems caused by breast size (physical wellbeing) and the effects of breasts on self-esteem, body image and confidence in social settings (psychosocial wellbeing). Scores of between 0 and 100 on the physical wellbeing (14-items) and psychosocial wellbeing (9-items) subscales were used, with higher scores denoting greater wellbeing. A score change of 5-points indicates a MCIC between pre- and post-surgical periods for each subscale[182] with change scores of greater than 20 indicating a 'very much' change[164].

Body satisfaction was measured in response to the question "How satisfied are you with your body shape?" on a NRS of 0-10, with higher scores indicating greater body satisfaction. There were no MCIC data available for this measure of body satisfaction.

Surgery outcomes were assessed postoperatively at 3, 6 and 12-months using subscales of the BREAST-Q instrument[134] . Satisfaction with outcomes (8-items), satisfaction with information (13-items) and satisfaction with nipples (5-items) were indicated by scores of between 0-100, with higher scores indicating greater satisfaction. At the 3-month follow-up measurement session, participants verbally reported the weight (g) of resected breast tissue and indicated the type of surgical approach, whether their surgery had been self-funded, and the approximate wait-time for the procedure. Complications during or following surgery that required intervention or any surgical revisions were also reported at this time.

12.3.2 Objective measures

The objective measures used are described in detail in Chapter 2 section 2.7. In brief, measurements of height (cm) and weight (kg) were used to calculate BMI (kg/m²). Dual energy X-ray absorptiometry (Lunar Prodigy, GE Healthcare Little Chalfont , UK) was used to assess BMD and body composition[198]. Bone mineral density assessed from axial scans was the average measure (g/cm²) taken from the left and right FN. Body composition measured in whole body scans quantified total lean mass (kg) and fat mass (kg).

Breast size was derived from measured bra size using over-bust and under-bust circumferences[206]. A tape measure was used to acquire circumferential distances (cm) which

were converted into a continuous BSS of between 0-18 (Appendix 4b). Breast ptosis was measured as the distance (cm) between the sternal notch and nipple averaged from both sides with participants in sitting. Breast splay was the measured distance from the left to the right nipple (cm). Bra fit (pass/fail) was assessed using professional criteria. No information regarding bra fit was provided to participants at the time of each assessment.

Upper back extensor muscle endurance was assessed using the isometric chest raise test[230]. There was no MCIC data available for this measure of upper back extensor muscle endurance but a time of ≥160s places women aged over 50 years above the 75th percentile for upper back extensor muscle endurance in relation to age-referenced norms[115].

Upper back mobility was assessed using photographic methods validated by Edmondston et al[100]. Preliminary work from this thesis identified a MDC threshold of 5.3° (refer to Chapter 3) and published data indicates that a thoracic extension range of motion of approximately 13° would typically be normal[101, 232].

Thoracic kyphosis was measured as a Cobb angle[234] from a single lateral thoracic X-ray. An intrinsic error of 5° is widely referenced for radiographic measures of thoracic kyphosis[236]. In the absence of a MCIC value, an angle >5° was used to indicate a change that was unlikely due to measurement error alone. The presence of thoracic vertebral fractures and osteoarthritis were assessed using the same lateral thoracic X-ray.

Posture was examined using three separate angles measured from lateral photographic images of participants in standing. Head (craniovertebral angle), upper back (cervicothoracic angle), and shoulder (shoulder protraction angle) posture were assessed using procedures deemed reliable in Chapter 3. In addition to normative data available for head[244], upper back[245] and shoulder posture[242], reference angles recorded for mature-aged women in the preliminary work of this doctoral research project were used for comparison (refer to Chapter 3 Table 3.1). In the absence of MCIC values for head, upper back and shoulder posture angles measured in this manner, normative data were used to judge the clinical meaningfulness of the angles measured preoperatively and postoperatively. In addition, MDC values that were determined for each respective angle in the preliminary work outlined in Chapter 3, were also used for reference. Angles of 3.3°, 2.6° and 4.4° represented the MDC for head, upper back and shoulder posture angles respectively (refer to Chapter 3, Table 3.1).

Sensitivity of upper back musculoskeletal tissues was assessed using digital algometry. Using the procedure determined to be reliable in preliminary work outlined in Chapter 3, the PPTs of six skeletal sites (spinous process of T2, T4, T6, T8, T10 and T12) and six muscular

sites (pectoralis major, levator scapulae, sternocleidomastoid, upper, middle and lower trapezius) were examined. Predetermined MDC values calculated in preliminary work were used to identify changes that were not the result of measurement error (refer to Chapter 3 Table 3.2) however changes deemed clinically important (MCIC) have not been previously established.

12.4 Statistical analysis

Data were analysed using SPSS version 24 (IBM, Chicago, IL). Descriptive data were presented as mean (SD) for numerical variables where appropriate and number (n) percentages (%) for categorical variables.

12.4.1 Data screening

Normality of numeric data at each time point were screened with Shapiro-Wilks test. To address the possibility of a Type II error, where a small sample size may have lacked the power to detect a deviation of the variable from normality[289], normality test results and frequency distributions for each variable were compared to those generated for the same variables in a larger sample (postmenopausal subset, n=119) as recommended by Curran-Everett[290]. A variable had to show a normal distribution in the larger postmenopausal subset for it to be accepted as normal in the smaller surgical sample. Consideration was also given to possible errors of repeated measures analyses using a small sample size and data were carefully examined to ensure confidence in the robustness of the statistical tests selected as outlined by Oberfeld and Franke[291].

12.4.2 Pre-to-post surgery changes

A one-way repeated measures ANOVA was used to compare the differences between the pre and post-surgery values of self-report and physical numeric characteristics showing normal distributions. Data were screened for outliers and assumptions of sphericity were checked. Where assumptions of sphericity were violated, as assessed by Mauchly's test of sphericity, a Greenhouse-Geisser correction was applied. Post-hoc analysis without adjustment for multiple comparisons (Least Significant Difference) identified the MD and 95%CI of those characteristics that were statistically significant between pre-surgery and post-surgery time points. Statistical significance was set at $p<0.05$. Non-parametric tests (Friedman's test) were used to confirm results. Any discrepancies between parametric and non-parametric test results were reported. For those characteristics showing a statically significant change, an estimate of population effect size (partial ω^2) was calculated using the formula $\omega^2 = (k-1)(F-1)/(k-1)(f-1) + nk$ previously described by Olenjnik and Algina[292] and Keppel[293] where and

k=number of levels of within-subjects factor, F = value of F-statistic, and n = number of participants. Values for ω^2 of between 0 and 1 indicated the strength of effect size with higher values indicating a stronger effect size[294]. In a sample of 11 participants measured over four time-points the study was powered to show a minimum within-subjects variability (partial eta squared) of 0.127 in any continuous outcome variable with 80% power and a confidence level of 95%[147]. As estimates of population effect size (partial ω^2) compensate for bias in partial eta squared, the study was suitably powered to detect partial ω^2 values ≥ 0.03. The power calculations for this study were post-hoc and revised down to account for the smaller than anticipated sample size.

A non-parametric equivalent (Friedman's test), which rendered a Chi-square value, was used to compare differences between pre and post-surgery values of characteristics showing non-normal distributions. Descriptive data were presented as median (interquartile range (IQR)). Pairwise comparisons using a post-hoc test without adjustment for multiple comparisons identified the time points between which medians were significantly different ($p < 0.05$).

Significant differences between pre and post-surgery percentages for categorical variables were described and an exact McNemar's test determined if changes between pre and each post-surgery time-point were statistically significant ($p < 0.05$).

12.4.3 Comparing pre-to-post surgery changes

For those characteristics measured on a continuous scale which showed statistically significant pre-to-post surgery improvement, a percentage mean change was calculated. Percentage mean change (%) was calculated as: $(V_2 - V_1)/V_1$ x 100, where V_1 was the mean pre-operative value and V_2 was the mean postoperative value[295]. Results were displayed graphically for each pre-to-post surgery time-point.

12.4.4 Clinically-relevant pre-to-post-surgery changes and covariates

To further explore the changes occurring following reduction mammoplasty, characteristics were examined against other criteria and referenced norms. Where prior literature had reported the MCIC scores for a self-report measure, these were used as a basis for exploring important changes. The MCIC is defined as the minimum change in score that is meaningful for patients[296]. For physical characteristics where MCIC data were largely not available, changes were first examined against MDC thresholds to evaluate whether changes fell outside the measurement error of the instrument. Where possible, the MDC values established in the preliminary work for this doctoral research project were used otherwise these values were drawn from prior literature where available and appropriate. Following

this, normative reference and epidemiological data were used to judge whether the changes observed in physical characteristics were clinically relevant.

Changes in characteristics, other than the breast, that demonstrated a clinically relevant change, defined as a change exceeding MCIC, MDC or notable referenced norms, were examined against clinical variables with the potential to influence the outcomes following reduction mammoplasty. Age, BMI, resected breast weight and satisfaction with surgery outcome were examined as four potential clinical covariates of interest. Using methods previously described[73], Pearson product-moment correlation coefficients (r) assessed the strength and significance ($p<0.05$) of linear relationships to identify the impact of these clinical covariates on characteristics pre and post-surgery. Postoperative values showing the greatest change were used. Correlations were interpreted as weak ($r<0.3$), moderate ($r=0.3$-0.5) or strong ($r>0.5$)[263].

12.5 Results

12.5.1 Participant characteristics

Fourteen women who were preparing for reduction mammoplasty, volunteered to participate in this aspect of the doctoral research project and underwent pre-surgery measures. Two participants withdrew from planned surgery and one participant withdrew from the study following surgery (refer to Chapter 2, Figure 2.3). Eleven participants with a mean (SD) age of 57.3 years (9.4 years) had complete datasets that were analysed. The mean (SD) height, weight, and BMI preoperatively were: 158.7cm (5.2cm), 74.1kg (13.0kg), and 29.4kg/m² (4.7kg/m²) respectively. Seven (64%) participants were in full or part-time employment and the majority (73%) of participants were postmenopausal. In response to an open-ended question, "back pain" was the most common reason cited for undergoing reduction mammoplasty reported by participants (Table 12.2).

Table 12.2 Participants reasons for undergoing reduction mammoplasty

Reason for reduction mammoplasty	n (%)
Back pain	10 (91)
Neck pain	5 (45)
Shoulder pain	3 (27)
Rashes under breast	2 (12)
Embarrassment	1 (9)
Physical activity limitation	1 (9)

12.5.2 Pre-surgery characteristics

Preoperative BSS values ranged from size 5 to 13. Self-reported bra band sizes ranged from size 10-18 and bra cup sizes ranged from a C-cup to G-cup. Ten (91%) participants, pre-surgery, were wearing ill-fitting bras as assessed against professional criteria and seven (64%) participants reported dissatisfaction with their bra fit (Table 12.3). The majority of participants (91%) were embarrassed by their breasts and all participants had a desire to change their breasts (Table 12.3). Upper back pain, with severity scores ranging from 2 to 8 on NRS, was reported by 10 (91%) participants pre-surgery (Table 12.3), all of whom reported UBP lasting more than 3-months.

12.5.3 Reduction mammoplasty characteristics

Ten (91%) participants had self-funded their surgery and had waited less than 6-months for the procedure. All participants underwent reduction mammoplasty under general anesthetic using traditional inverted-T scar methods. All surgeries were uncomplicated and there were no post-surgical complications requiring intervention. Resected breast weights ranged from 220-1135g for the left breast and from 275-1060g for the right breast. The mean (SD) total resected breast weight per participant was 964.9g (393.9g). There were no revisions during the 12-month follow-up period. Levels of satisfaction with the outcome of surgery were highest at 3-months post-surgery (Table 12.3). There were high levels of satisfaction with information regarding the surgery and satisfaction with nipples across the sample. Participants remained satisfied with the outcomes of surgery across the 12-month post-surgical period (Table 12.3).

12.5.4 Pre-to-post-surgery changes: self-report characteristics

Breast and bra fit perceptions: Breast satisfaction scores significantly improved following surgery with the greatest change recorded between pre and 6-months post-surgery (MD: 47.27, 95%CI: 16.13 to 78.41) (Figure 12.1). Of all the characteristics examined, breast satisfaction recorded the largest effect size (0.57) (Table 12.3). All participants recorded a change in breast satisfaction that exceeded a MCIC of 5-points by 12-months post-surgery (score change range: 5 to 100). Participants reported significantly less breast embarrassment following surgery (p=0.004) and significantly fewer participants expressed a desire to change their breasts (p=0.004). Despite these improvements, participants showed no change in their satisfaction with their bra fit following surgery (p=0.062) (Table 12.3).

Pain characteristics: All self-reported ratings of pain severity decreased significantly from pre to 3-months post-surgery, including UBP (MD: -2.36, 95%CI: -4.45 to -0.19), neck pain disability (-7.36, 95%CI: -12.41 to -2.32), and shoulder pain (MD: -3.73, 95%CI: -6.49 to -

0.97 (Table 12.3). Minimum clinically important changes were recorded for UBP, neck pain disability and shoulder pain (Table 12.3). For UBP severity, the improvements were greatest between pre and 6-months post-surgery (MD:-3.55, 95%CI: -6.46 to -0.64) and improvements remained significantly different at 12-months post-surgery (Figure 12.2). There was a significant reduction in the risk of pain chronicity (OMPSQ scores) from pre-surgery to post-surgery. Scores on the OMPSQ trended downwards with time after surgery (Table 12.3).

Physical activity levels: Participants were significantly more active at 6 and 12-months post-surgery compared to pre-surgery. The greatest change was recorded between pre and 12-months post-surgery (MD: 9.00, 95%CI: 2.71 to 15.30) (Table 12.3), but this change was below the referenced MCIC (14-points) for the HAP measure[171].

Health-related quality of life: Physical component summary scores (of the SF-36) increased significantly from pre-to-post surgery with the greatest difference, recorded between pre and 12-months post-surgery, being a mean improvement of 7.96 (95%CI: 0.80 to 15.12) which exceeds the 5-point MCIC (Table 12.3). According to non-parametric tests changes in SF-36 PCS scores were approaching significance (p=0.058). There was no significant changes in SF-36 MCS scores (p=0.203). Breast-specific HRQoL improved significantly after surgery and both subscales on the BREAST-Q recorded an MCIC of >5-points. Breast-related psychosocial wellbeing increased by the greatest amount between pre and 3-months post-surgery (MD: 36.82, 95%CI: 14.30 to 59.34) whereas breast-related physical wellbeing showed the greatest improvements between pre and 12-months post-surgery (MD: 26.10, 95%CI: 8.78 to 43.40). The effect sizes recorded for these characteristics were amongst the largest recorded in the study (Table 12.3).

Body satisfaction: Ratings of body satisfaction showed significant improvement from pre to 3-months post-surgery (MD: 1.73, 95%CI: 0.95 to 2.50) and this continued to improve to 6-months post-surgery, after which ratings dropped back to levels that were only slightly higher than pre-surgery levels (Table 12.3).

Table 12.3 Data summary of pre-to-post surgery changes in self-report and physical characteristics

Characteristic		Pre-surgery mean (SD)	3m post-surgery mean (SD)	6m post-surgery mean (SD)	12m post-surgery mean (SD)	p-value	ES[i]	Clinically-relevant change[j]
Breast and bra fit perceptions								
Breast satisfaction (BREAST-Q)		22.1(18.5)	**67.4 (23.0)[a]**	**69.36 (23.8)[a]**	**67.4 (23.3)[a]**	**<0.001[b]**	**0.57**	MCIC: ≥5-points
Bra Fit satisfaction[c]	Yes	4 (36.4)	9 (81.8)	9 (81.8)	9 (81.8)	0.062[d]	-	-
	No	7 (63.6)	0 (0.0)	0 (0.0)	0 (0.0)			
Breast embarrassment[c]	Yes	10 (90.9)	1 (9.1)	1 (9.1)	**1 (9.1)[a]**	**0.004[d]**	**-**	-
	No	1 (9.1)	**10 (90.9)[a]**	**10 (90.9)[a]**	**10 (90.9)[a]**			
Desire to change breasts[c]	Yes	11 (100.0)	**2 (18.2)[a]**	**2 (18.2)[a]**	**2 (18.2)[a]**	**0.004[d]**	**-**	-
	No	0 (0.0)	**9 (81.8)[a]**	**9 (81.8)[a]**	**9 (81.8)[a]**			
Pain characteristics								
UBP presence (yes/no)[c]	Yes	10 (90.9)	5 (45.5)	2 (18.2)	5 (45.5)	0.062[d]	-	-
	No	1 (9.1)	6 (54.5)	9 (81.8)	6 (54.5)			
UBP severity (NRS)		4.5 (2.2)	**2.1 (2.6)[a]**	**0.9 (2.0)[a]**	**1.6 (2.1)[a]**	**<0.001[b]**	**0.16**	MCIC:≥ 2-points
Neck pain disability (NDI)		13.8 (6.9)	**6.5 (5.9)[a]**	**7.1 (6.1)[a]**	**6.6 (5.8)[a]**	**<0.001[b]**	**0.42**	MCIC:≥ 5-points
Shoulder pain severity (NRS)		5.1 (2.2)	**1.4 (2.4)[a]**	**1.6 (2.2)[a]**	**2.0 (2.5)[a]**	**0.001[b]**	**0.30**	MCIC:≥ 2-points
Pain chronicity (OMPSQ)		50.4 (8.4)	**34.5 (17.8)[a]**	**32.0 (14.5)[a]**	**29.3 (17.9)[a]**	**<0.001[b]**	**0.43**	-
Physical activity								
Adjusted activity score (HAP AAS)		65.4 (11.4)	69.9 (12.5)	**72.2 (13.2)[a]**	**74.4 (12.8)[a]**	**0.005[b]**	**0.22**	MCIC≥14-points
Health-related quality of life								
Physical component summary (PCS) score (SF-36)		43.2 (5.3)	**50.2 (7.8)[a]**	50.4 (10.4)	**51.2 (10.7)[a]**	**0.007[b]**	**0.21**	MCIC: ≥5-points
Mental component summary (MCS) score (SF-36)		46.9 (7.5)	50.2 (5.2)	51.7 (9.3)	50.8 (7.6)	0.203[b]		MCIC: ≥5-points
Breast-related psychosocial wellbeing (BREAST-Q)		39.7 (9.9)	**76.6 (20.3)[a]**	**75.9 (21.8)[a]**	**72.1 (24.7)[a]**	**<0.001[b]**	**0.54**	MCIC: ≥5-points
Breast-related physical wellbeing (BREAST-Q)		54.0 (11.7)	**77.5 (12.6)[a]**	**75.7 (10.9)[a]**	**80.1 (13.3)[a]**	**<0.001[b]**	**0.52**	MCIC: ≥5-points
Satisfaction								
Body satisfaction (NRS)		3.3 (1.9)	**5.0 (2.0)[a]**	**5.3 (1.9)[a]**	4.6 (1.9)	**0.006[b]**	**0.21**	-
Outcomes of surgery								
Satisfaction with outcome (BREAST-Q)		-	89.6 (18.9)	87.6 (17.0)	85.8 (19.1)	-	-	-
Satisfaction with information (BREAST-Q)		-	78.6 (20.4)	73.5 (26.0)	80.8 (23.0)	-	-	-
Satisfaction with nipples (BREAST-Q)		-	84.3 (19.9)	69.6 (24.5)	77.5 (30.6)	-	-	-
Anthropometric characteristics								
Height (cm)		158.7 (5.2)	158.7 (4.8)	158.8 (4.9)	158.7 (4.8)	0.630[b]	-	-
Weight (kg)		74.1 (13.0)	73.8 (11.8)	74.2 (12.0)	74.7 (11.7)	0.827[b]	-	-
BMI (kg/m²)		29.4 (4.7)	29.3 (4.1)	29.4 (4.3)	29.7 (4.4)	0.725[b]	-	-
Bone mineral density								
BMD (g/cm²)		0.98 (0.15)	-	**0.96 (0.15)[a]**	**0.95 (0.15)[a]**	**0.018[b]**	**0.21**	**-**
Body composition								
Lean mass (kg)		39.2 (4.3)	39.4 (4.2)	38.7 (4.7)	39.0 (4.4)	0.149[b]	-	-
Fat mass (kg)		32.5 (9.4)	32.1 (8.2)	32.9 (8.8)	32.5 (8.0)	0.754[b]	-	-

Self-report (rows: Breast and bra fit perceptions through Outcomes of surgery)

Physical (rows: Anthropometric characteristics through Body composition)

Characteristic		Pre-surgery mean (SD)	3m post-surgery mean (SD)	6m post-surgery mean (SD)	12m post-surgery mean (SD)	p-value	ES[i]	Clinically-relevant change[j]
Breast characteristics								
Breast size (BSS)		8.5 (3.3)	**6.0 (1.8)[a]**	**6.6 (1.3)[a]**	**6.1 (1.6)[a]**	**0.001[b]**	0.30	-
Breast ptosis (cm)		28.0 (4.0)	**19.7 (1.7)[a]**	**19.8 (2.3)[a]**	**19.5 (1.9)[a]**	**<0.001[b]**	0.73	-
Breast splay (cm)		26.0 (4.3)	**22.5 (2.7)[a]**	**22.7 (2.7)[a]**	**22.7 (2.5)[a]**	**<0.001[b]**	0.53	-
	Pass	1 (9.1)	5 (45.5)	**6 (54.5)[s]**	**6 (54.5)[a]**			
Bra Fit[c]	Fail	10 (90.0)	4 (36.4)	**3 (27.3)[s]**	**3 (27.3)[a]**	**0.031[d]**	-	-
	N/A	0	2 (18.2)	2 (18.2)	2 (18.2)			
Upper back characteristics								
Upper back extensor muscle endurance (s)		136.7 (81.4)	164.3 (106.6)	177.4 (108.7)	167.5 (102.4)	0.234[b]	-	time≥160s
Upper back mobility (°)		8.6 (6.6)	7.3 (5.9)	8.9 (5.3)	8.8 (5.8)	0.798[b]	-	MDC: 5.3°
Thoracic kyphosis								
Radiographic Cobb angle (°)		40.7 (12.2)	-	43.2 (11.7)[e f]	44.5 (12.9)[e]	0.083[b]	-	MDC: 5°
Thoracic spine morphology								
Thoracic vertebral fracture[c]	Yes	3 (27.3)	-	4 (36.4)	4 (36.4)	N/A	-	-
	No	8 (72.7)	-	7 (63.6)	7 (63.6)			
Thoracic osteoarthritis[c]	Nil-mild	8 (72.7)	-	5 (55.6)[c]	7 (63.6)	1.00[d]	-	-
	Moderate-severe	3 (27.3)	-	4 (44.4)	4 (36.4)			
Posture								
Head posture (°)		40.3 (5.1)	**44.1 (6.1)[a]**	**44.1 (4.8)[a]**	41.0 (6.1)	**0.010[h]**	0.25	MDC: 3.3°
Upper back posture (°)		104.8 (5.8)	100.9 (6.5)	102.4 (5.0)	104.9 (4.9)	0.191[h]	-	MDC: 5.6°
Shoulder posture (°)		35.0 (10.8)	31.1 (11.4)	34.0 (11.8)	37.1 (10.4)	0.057[b]	-	MDC: 4.4°
Upper back musculoskeletal tissue sensitivity (PPTs)[g]								
PPT T2 (kPa)		348.7 (237.0)	308.0 (217.3)	405.7 (252.0)	347.0 (213.0)	0.615[h]	-	MDC:192.2kPa
PPT T4 (kPa)		282.3 (271.7)	381.3 (270.3)	369.0 (182.0)	368.0 (286.3)	0.445[h]	-	MDC:192.0kPa
PPT T6 (kPa)		352.7 (299.3)	471.3 (214.7)	378.0 (152.3)	395.0 (209.3)	0.263[h]	-	MDC: 240.2kPa
PPT T8 (kPa)		317.7 (190.3)	449.7 (379.7)	447.7 (263.0)	438.0 (308.3)	0.138[h]	-	MDC: 196.8kPa
PPT T10 (kPa)		458.7 (329.0)	394.0 (260.3)	474.3 (290.3)	394.0 (315.7)	0.359[h]	-	MDC: 241.8kPa
PPT T12 (kPa)		413.0 (210.3)	444.3 (236.7)	432.7 (155.7)	424.7 (305.7)	0.078[h]	-	MDC: 257.4kPa
PPT Pectoralis major (kPa)		197.67 (84.7)	268.7 (112.3)	200.7 (72.0)	184.0 (99.7)	0.145[h]	-	MDC: 92.4kPa
PPT Levator scapulae (kPa)		347.7 (233.0)	**551.0 (274.3)[a]**	**440.0 (180.7)[a]**	453.7 (244.0)	**0.007[h]**	-	MDC: 192.0kPa
PPT sternocleidomastoid (kPa)		110.3 (53.0)	91.6 (83.3)	93.0 (38.0)	97.3 (65.7)	0.359[h]	-	MDC: 70.3kPa
PPT Upper trapezius (kPa)		293.3 (120.7)	296.0 (206.0)	368.3 (165.0)	316.7 (214.7)	0.071[h]	-	MDC: 223.7kPa
PPT middle trapezius (kPa)		375.7 (270.0)	456.7 (435.3)	447.7 (272.7)	430.0 (225.3)	0.664[h]		MDC: 198.9kPa
PPT Lower trapezius (kPa)		379.7 (265.3)	**561.4 (327.7)[a]**	491.0 (202.0)	481.3 (273.7)	**0.002[h]**		MDC: 166.1kPa

[a] Significantly different from pre-surgery; [b] Analysed with repeated measures ANOVA; [c] Data presented as n (%); [d] Analysed using McNemar's test [e] One participant excluded; [f] Two missing values; [g] Data presented as medians (interquartile range); [h] Analysed using Friedman's test; [i] Population effect size (ω²) calculated for significant changes in characteristics analysed using repeated measures ANOVA; [j] Data presented where available. **Abbreviations**: ES - Effect size; BMI - Body mass index; BMD - Bone mineral density; BSS - Breast size score; NRS - Numerical rating scale; NDI - Neck Disability Index; OMPSQ - Orebro Musculoskeletal Pain Screening Questionnaire; HAP AAS - Human Activity Profile adjusted activity score; SF-36 - Medical Outcomes Study Short-Form 36 Health Survey; PCS: Physical component summary; MCS - Mental component summary; PPT - Pressure pain threshold
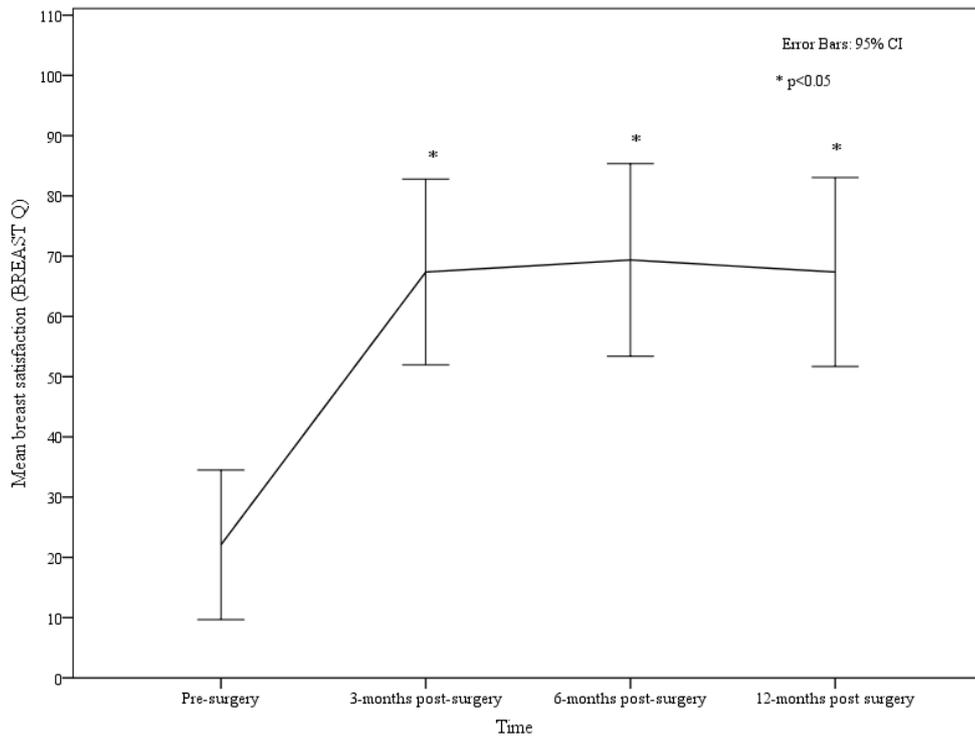
Figure 12.1 Pre-to-post-surgery changes in breast satisfaction
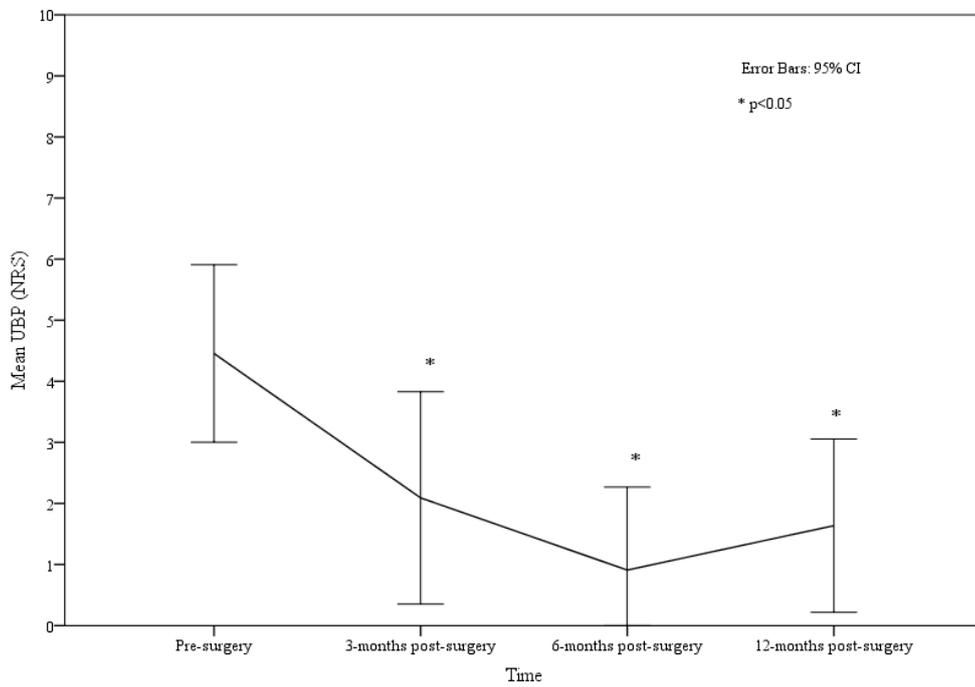
Figure 12.2 Pre-to-post-surgery changes in upper back pain severity

12.5.5 Pre-to-post surgery changes: physical characteristics

Anthropometry: There were no significant changes in anthropometric or body composition measures throughout the study (p>0.05). Bone mineral density reduced significantly but by minimal amounts from pre-surgery to 6-months post-surgery (MD: -0.023g/cm², 95%CI: -0.008 to -0.038g/cm²) and from pre-surgery to 12-months post-surgery (-0.031g/cm², 95%CI: -0.009 to -0.054g/cm²) (Table 12.3).

Breast characteristics: Significant reductions in breast size (MD: -2.73 sizes, 95%CI: -5.23 to -0.22 sizes), breast ptosis (MD: -8.30cm, 95%CI: -12.23 to -4.36cm) and breast splay (MD: -3.55cm, 95%CI: -5.99 to -0.65cm) occurred throughout the duration of the study (Table 12.3). Following surgery, two participants reported that they no longer wore a bra but amongst those who did wear a bra, significantly more participants wore a bra that was correctly fitted when judged against professional criteria (p=0.031).

Upper back characteristics: Mean upper back extensor muscle endurance trended towards an improvement following surgery (Figure 12.3) but changes were not significant (p=0.234) (Table 12.3). Mean upper back endurance times did however increase to exceed 160s (the 75th percentile referenced norm) at all post-surgery time-points. Upper back mobility remained unchanged following surgery and mean differences in upper back mobility between pre and post-surgery were below MDC values (5.32°) at all follow-up time-points (Table 12.3).

Thoracic kyphosis: One participant who was diagnosed with a new vertebral fracture in the postoperative period was excluded from analysis of thoracic kyphosis angles at 6 and 12-months post-surgery because a new fracture may confound any changes measured in thoracic kyphosis. Radiographic Cobb angles progressively increased from pre-to-12-months post-surgery but these changes in thoracic kyphosis were not significant (p=0.083) (Table 12.3).

Thoracic spine morphology: There were no significant changes in the number of vertebral fractures or the amount of intervertebral joint osteoarthritis amongst participants from the pre-to-post surgery periods (Table 12.3).
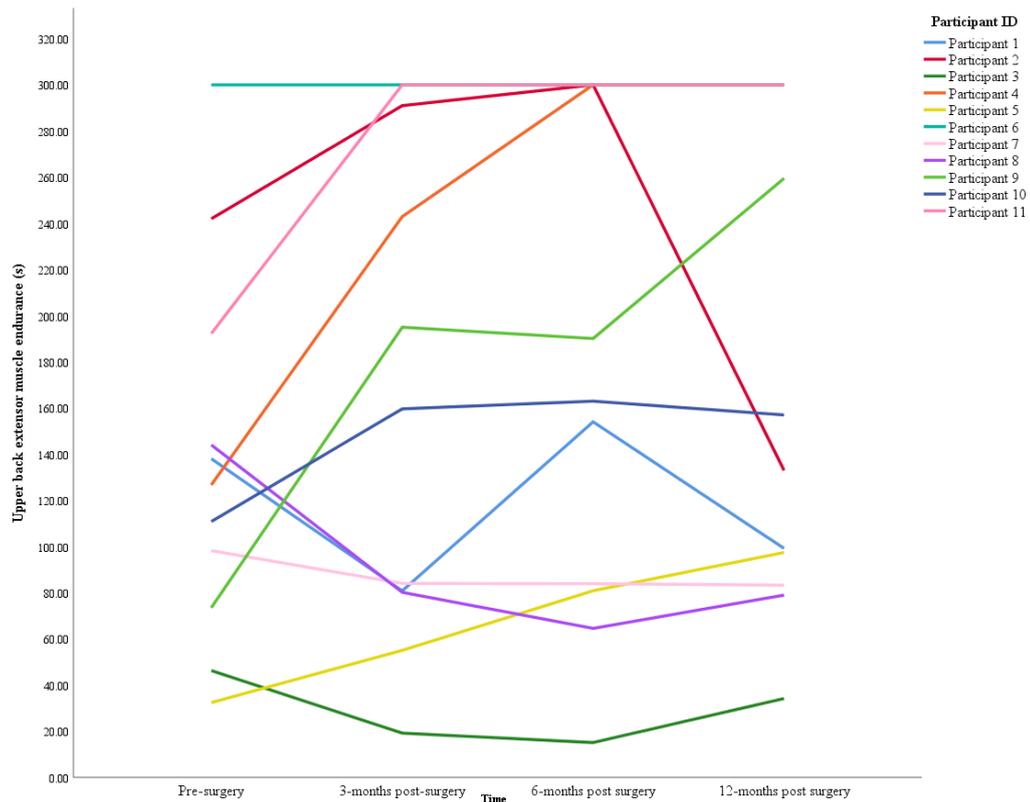
Figure 12.3 Pre-to-post-surgery changes in upper back extensor muscle endurance

Posture: Significant improvements in head posture (Figure 12.4) were measured between pre-surgery at both 3-months (p=0.007) and 6-months post-surgery (p=0.002). Changes in head posture between pre and 12-months post-surgery were, however, not significant (Table 12.3). Mean differences in head angles between pre and post-surgery at 3-months and 6-months exceeded MDC of 3.33° and non-parametric tests confirmed the changes as being statistically significant (p=0.010). The percentage improvements in head posture were however relatively small (2-10%) (Figure 12.5).

When non-parametric tests were run, the changes in upper back posture between pre and 6-months post-surgery were not significant (p=0.191), indicating a likely Type I error in the repeated measures ANOVA result. Confirming that the changes in upper back posture were not significantly different between pre and post-operative periods was the small difference in angle between these time points which fell below a MDC threshold of 2.58° (Table 12.3).

Shoulder posture remained unchanged from pre-to-post surgery (p=0.057) (Table 12.3). It was noted that shoulder posture angles, in general, were small with both pre and post-surgery angles considerably lower than a normative angle of 47.6°.
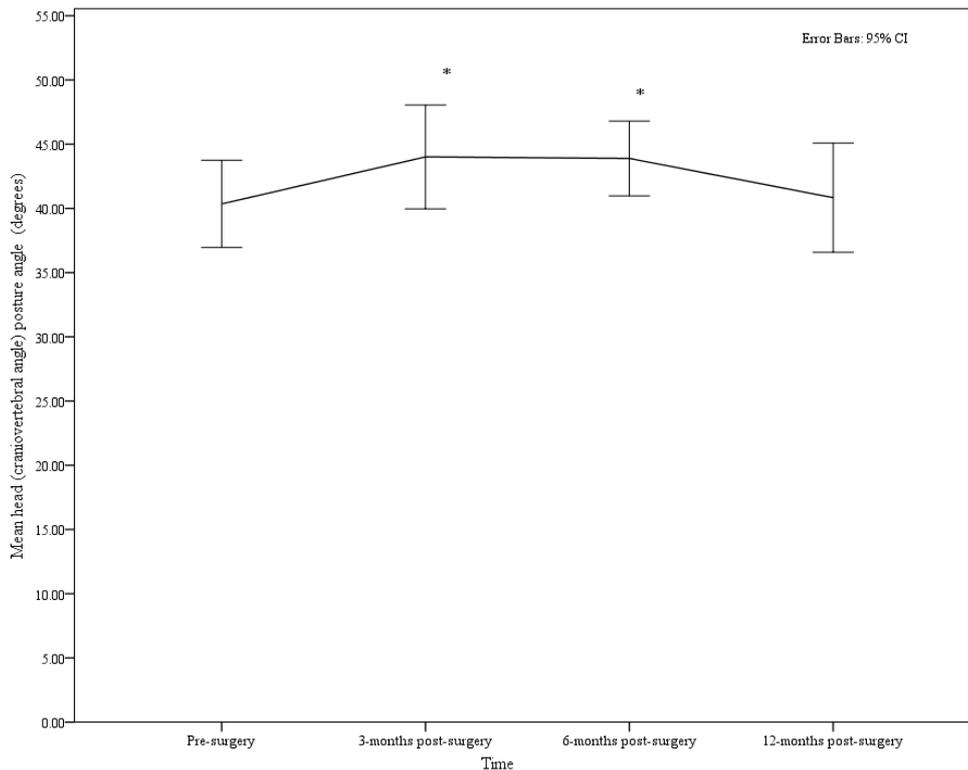
Figure 12.4 Pre-to-post-surgery changes in head posture

Upper back musculoskeletal tissue sensitivity: All PPT data were analysed using non-parametric tests as data were positively skewed. There was a trend towards higher PPTs being recorded post-surgery compared to pre-surgery across all skeletal and muscular sites, however, levator scapulae ($X^2 = 12.06$, p=0.007) and lower trapezius ($X^2 = 15.11$, p=0.002) were the only anatomical sites that showed significant changes from pre to post surgery (Table 12.3). Levator scapulae was the only site to maintain significantly improved change in sensitivity at 6-months post-surgery (p=0.002). There were no significant differences in PPTs across all sites recorded between pre and 12-months post-surgery (Table 12.3). It cannot be excluded that the use of non-parametric tests in the analysis of PPT data did not lead to a Type II error. However, this seems unlikely when the change in PPT values from pre-to-post-surgery were considered. Mean and median differences noted at each anatomical site between pre and post-surgery were consistently under a threshold of MDC, providing confidence that the results are showing a true non-significant change in PPT for the majority of tissues.

201

12.5.6 The nature of characteristics changing following reduction mammoplasty

There were a greater total number of self-report characteristics than physical characteristics showing a significant pre-to-post surgery improvement (Figure 12.5). Of the characteristics that were self-reported, breast satisfaction showed the greatest overall percentage improvement (Figure 12.5). This improved by 214% between pre-surgery and 6-months post-surgery.

Breast-related psychosocial wellbeing also showed large percentage improvements with the greatest (97%) recorded between pre-surgery and 3-months post-surgery (Figure 12.5).

Upper back pain improved by 80% between pre-surgery and 6-months post-surgery and this was the greatest change observed out of all the measured pain characteristics (Figure 12.5).

In general the physical characteristics showed much smaller percentage improvements than self-reported characteristics. Pressure pain thresholds for the levator scapulae and lower trapezius showed maximum percentage improvement of 59% and 48% respectively and these were both recorded between pre-surgery and 3-months post-surgery (Figure 12.5). The significant changes in head posture were smaller still and this was reflected in a 2-10% improvement from pre-to-post surgery (Figure 12.5).
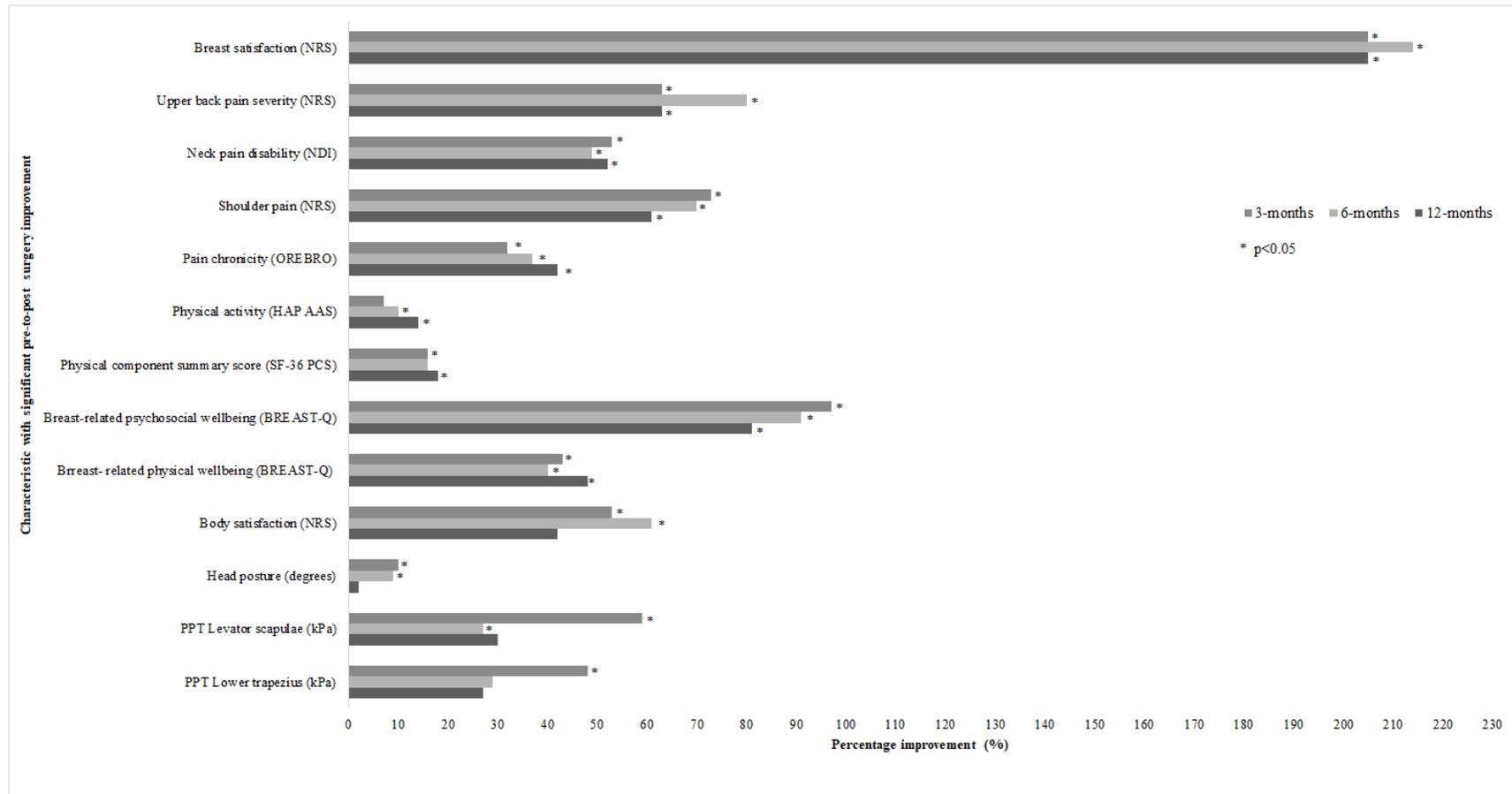
Figure 12.5 Comparing characteristics with a significant pre-to-post surgery improvement using percentage mean change.

12.5.7 Clinically-relevant pre-to-post-surgery changes and covariates

With the exception of breast satisfaction, there were no significant correlations between potential clinical covariates of age, BMI, total resected breast weight, or satisfaction with surgery outcome and the pre or post-surgery values for characteristics showing clinically relevant change (Table 12.4). Post-surgery breast satisfaction correlated strongly with satisfaction with outcome from surgery ($r=0.72$, p=0.013).

Table 12.4 Pearson product-moment correlation coefficients between clinical covariates and clinically-relevant changes in self-report and physical characteristics

Characteristics	Clinical covariates							
	Age		BMI		Resected breast weight		Satisfaction with outcome	
	pre	post	pre	post	pre	post	pre	post
Breast and bra fit perceptions								
Breast satisfaction[b]	0.05	0.01	-0.27	0.26	-0.26	0.15	-0.43	**0.72**
Pain characteristics								
UBP severity[b]	-0.13	0.38	0.36	0.09	0.19	0.06	0.06	0.27
Neck pain disability[a]	-0.24	-0.26	0.56	0.51	0.39	0.35	0.22	0.05
Shoulder pain severity[a]	-0.19	0.38	0.05	0.16	0.41	0.39	0.45	0.35
Pain chronicity[c]	0.25	0.13	0.44	0.11	0.32	0.31	0.09	-0.22
Health-related quality of life								
Physical component summary scores[c]	0.10	-0.20	-0.55	-0.22	-0.37	-0.10	-0.14	0.30
Breast-related psychosocial wellbeing[a]	0.06	-0.39	-0.50	0.38	-0.52	0.15	-0.59	0.35
Breast-related physical wellbeing[c]	0.51	0.26	-0.34	-0.12	-0.41	-0.03	-0.38	0.54
Upper back characteristics								
Upper back extensor muscle endurance[b]	-0.02	0.30	-0.26	-0.30	-0.06	-0.31	0.02	0.08
Posture								
Head posture[b]	-0.43	-0.48	-0.51	-0.19	-0.44	-0.38	-0.52	-0.27

[a] 3-month post-surgery value used; [b] 6-month post-surgery value used; [c] 12-month post-surgery value used. Bolded figure show correlation that was significant (p<0.05). **Abbreviations:** UBP - Upper back pain; BMI - Body mass index; pre - Pre-surgery; post - Post-surgery

12.6 Discussion

The aim of this chapter was to examine the self-report and physical characteristics that change following reduction mammoplasty with the purpose of identifying trends in the nature, rate and clinical relevance of improvements that occur. This work presents the largest collection of characteristics to have been examined longitudinally before and after reduction mammoplasty. The distinctive findings have been that the improvements observed following reduction mammoplasty are predominantly self-report in nature, immediate (within 3-months post-surgery), enduring (maintained up to 12-months), and independent of resected breast weight.

From the baseline (pre-surgery) data collected in this study, the clinical impact of large breast sizes on subjective markers were clearly evident. Participants preoperatively had

moderate levels[152] of pain across multiple body regions, had below referenced norms for SF-36 PCS scores[176], and were at high risk of pain chronicity[195]. Preoperative BREAST-Q scores for breast-related themes of breast satisfaction, physical and psychosocial wellbeing were at least 20-points below normative values[163], illustrating the health burden associated with large breasts. Physical activity levels by contrast, were relatively normal, with overall scores indicating a moderately active sample preoperatively[169].

"Back pain" was reported as the reason for undergoing reduction mammoplasty by the majority (91%) of our sample and the majority (91%) of participants also reported UBP prior to surgery. Upper back pain is reported to affect between 82%[25] and 97%[26] of women prior to reduction mammoplasty. With a similar prevalence, our small sample therefore seemed representative of women who typically undergo reduction mammoplasty. In our surgical sample, five of the six most common reasons given for pursuing reduction mammoplasty related to physical complaints. This was an expected finding in older women undergoing reduction mammoplasty[44] and one that provides further validation that women of this age are seeking functional, rather than cosmetic, gains from the procedure[43, 45, 46].

The findings of this study are consistent with the self-reported benefits of reduction mammoplasty noted in previous literature[25, 26, 40, 41, 46, 48, 69, 70, 73,75-77]. Changes in self-report characteristics consistently trended towards improvement. The main pattern of change for the majority of self-report characteristics was that considerable change occurred within 3-months post-surgery followed by either a plateau or continued improvement beyond this to 12-months post-surgery. Self-report characteristics with significant and clinically important changes, that were unlikely attributable to other clinical covariates, were: UBP severity, neck pain disability, shoulder pain severity, breast-related psychosocial wellbeing, and breast-related physical wellbeing. Changes in SF-36 PCS scores may also be considered on this list as the improvements in this characteristic were above the level of MCIC[297]. Breast satisfaction also showed a significant and meaningful change but this was strongly related to how satisfied participants were with the outcome of their surgery (r=0.72). Strong correlations between breast satisfaction and satisfaction with the outcome of surgery have been reported previously[73, 298] and our results further highlight how important it is for the surgical outcome to meet patients' expectations to ensure overall patient satisfaction.

The self-reported benefits of reduction mammoplasty are well-understood. The improvements in generic HRQoL[46, 71, 72], breast-specific HRQoL[73, 298], anxiety/depression[78] and body image[75] reported previously, have been observed as early as 1-month post-surgery[72, 73, 78] and with total breast resection weights of less than 750g[75]. The findings from this chapter complement those that have already illustrated that the reduction of large breasts

has profound benefits for aspects of health and psychological wellbeing and that these benefits are conferred irrespective of the amount of breast tissue removed. In addition, it demonstrates that the benefits to breast-related physical and psychosocial wellbeing and satisfaction are possible in women of older ages (mean age 57 years) than have been reported previously. Women of menopausal age or above are not widely represented in previous research on the outcomes of reduction mammoplasty for reasons that menopausal changes and ageing could influence the variables being measured. Whilst we do acknowledge this as a possibility, there is also no reason to believe that our measures are not reflecting the true benefits of this surgery in a sample of women who were older and largely postmenopausal.

The scale of improvements observed in the surgical sample were comparable to those previously seen. The widely documented significant relief from back pain/UBP following reduction mammoplasty[25, 26, 40-42, 69, 299] for example, commonly sees women shift from moderate to mild levels of pain on VAS[25, 40]. The largest mean change that has been reported in VAS is from preoperative values of 69.5 reducing to 13.3 on a 100mm VAS by 6-month post-surgery[40]. In the current study, despite being the most prevalent preoperative symptom, UBP was largely rated at mild severities (NRS<5) throughout the study. Upper back pain described by our sample, showed a significant 80% improvement and mean change over time of greater than the MCIC of 2-points, which is a potent and comparable clinical outcome. In addition, we observed that improvements in UBP occurred in women with relatively small mean total resection weights (964.91g).

Average resection weights of 1600g[26] and 1184g[25] have been previously recorded against improvements in UBP. Furthermore, improvements in UBP appear to be independent of the amount of breast tissue resected[25, 26, 41, 42] and our findings reflect this. In contrast, Berberoglu et al[40] who reported the greatest changes in 'back pain' severity with resection weights ranging from 363g to 1900g, described a positive correlation between the amount of tissue removed and the reduction in back pain. An important ongoing issue related to this, is whether minimum resection amounts should be included as criterion against which reduction mammoplasty is deemed to be a procedure of medical necessity[283, 284]. If preoperative symptoms such as UBP improve, regardless of the amount of tissue removed, then the criterion would seem superfluous.

A measure of pain chronicity risk has, to the best of our knowledge, not been previously recorded in women seeking reduction mammoplasty. Our findings demonstrate the potential value of reduction mammoplasty in changing this important clinical indicator which could have long-term potential benefits[300]. Whilst the OMPSQ was not intended as a PROM, by using it preoperatively and postoperatively to screen risk, we have identified from our pre-

surgery data, the potential for large breasts to contribute to long-term pain and disability risk, and, from our post-surgery data, for reduction mammoplasty to mediate this risk.

Physical component summary scores that normalise following reduction mammoplasty have been observed previously in larger studies of HRQoL amongst women undergoing reduction mammoplasty[70, 74, 172]. The amount and rate by which SF-36 PCS scores improved in the surgical sample were also comparable to those noted previously[70, 74, 172]. Consistent with two prior studies[77, 172], our findings showed that changes in SF-36 PCS scores were significant whereas changes in SF-36 MCS scores were not. This suggests that the benefits of reduction mammoplasty have a greater impact on physical aspects of HRQoL which relate to improvement in pain and/or physical function.

Of the remaining self-reported characteristics to improve significantly, breast-related physical and psychosocial wellbeing are also worthy of discussion in terms of the scale of their improvement. Postoperative scores of 70/100 or more for breast-related physical and psychosocial wellbeing using BREAST-Q were comparable to those observed by Cabral et al[73] in their sample of 107 women (mean age 34 years) within 1-month post-surgery, and by Cordiddi et al[76] in their study of 38 women (mean age 36 years) within 6-weeks post-surgery. The immediate positive effect of reduction mammoplasty on wellbeing and satisfaction captured on subscales of the BREAST-Q suggests the effects of reduction mammoplasty are relatively instantaneous. With scores stable at 12-months post-surgery, our data also show the long-term effects of reduction mammoplasty on these breast-related themes.

Changes in physical characteristics following reduction mammoplasty amongst our participants were less obvious than changes in self-reported characteristics. Furthermore, not all physical characteristics improved. Overall, it was unexpected that there would be so few physical characteristics to show a positive change following reduction mammoplasty. For characteristics that showed positive change, the changes were largely statistically non-significant, but most did gradually trend towards a continuing improvement to 12-months post-surgery, suggesting a potentially slower rate of change.

Upper back extensor muscle endurance was the only physical characteristic to show a meaningful improvement from pre-to-post surgery. This improvement, whilst not significant, did reflect a change that may be considered clinically relevant where mean postoperative endurance times on the isometric chest raise test increased to exceed the 75th percentile for age-referenced norms[115]. Of note, six participants (55%) exceeded a hold time of 160s (75th percentile) at some point following surgery which was a notable improvement from pre-

surgery where only 3 (27%) participants were able to reach this mark . Upper back extensor muscle endurance is often lower in women with larger breasts (refer to Chapter 9) and lower levels of endurance are associated with greater likelihood and severity of UBP (Chapter 8). As a characteristic with relevant ties to both breast size and UBP, this study has now also demonstrated that upper back extensor muscle endurance is a characteristic that improves with a reduction in breast size. This provides support for considering upper back extensor muscle endurance as a characteristic worth clinically targeting in women with large breasts that may be related to their UBP.

Prior research on the outcomes of reduction mammoplasty have largely focused on thoracic kyphosis as a physical characteristic of interest. Significant changes in thoracic kyphosis following reduction mammoplasty are well-documented[40, 51, 53], but have been mostly observed in women with macromastia, where breast weight exceeds 3% of body weight[58] and also in those who undergo very large breast resections (total resection> 2000g)[40, 51]. Changes in thoracic kyphosis are thought to be relevant to clinical symptoms such as UBP. However, only one study has previously formally assessed 'back pain' in relation to thoracic kyphosis following reduction mammoplasty. In 40 women (aged 26-48 years) 6-months following reductions of between 363g and 1900g, there was an 81% improvement reported in pain severity with average changes in thoracic kyphosis angles of 17°[40]. It is of interest that in our surgical sample, an 80% improvement in UBP occurred without a significant change in thoracic kyphosis.

The mean change in thoracic kyphosis angle of 3.8° that was recorded in our surgical sample at 12-months post-surgery following average breast resections of 964g, was marginally greater than that recorded by Karaaslan et al[52] who also reported no significant change in thoracic kyphosis following reduction mammoplasty. Karaaslan et al[52] conducted their study with a larger and younger (mean age 34 years) sample but, with average breast resections of 807g and preoperative thoracic kyphosis angles of 40.5°, their sample characteristics were similar to those in our surgical sample. It is of interest that in young women with a mean preoperative thoracic kyphosis angle of 40.5°[52], and in our surgical sample with a mean preoperative thoracic angle of 40.7°, no change in thoracic kyphosis was observed. In all of the studies[40, 51] with the exception of one[50], where significant changes in thoracic kyphosis following reduction mammoplasty have been reported, women with much larger preoperative thoracic kyphosis angles (>57.3°) have been assessed. This brings into question whether changes in thoracic kyphosis angles postoperatively may be related to how severe thoracic kyphosis is in women preoperatively. It is possible that benefits such as a reduction

in thoracic kyphosis may only be experienced by some women, those with very large/abnormal thoracic kyphosis angles preoperatively.

Head posture was the only physical characteristic showing a significant change that exceeded a threshold of MDC, albeit marginally. Preoperatively, mean head posture angles of less than 49° indicated that the majority of our sample had a forward head posture which were in the normative range for 75 to 85 year-old women (41.20°)[280]. Although the changes seen in head posture were significant by 6-months post-surgery, the improvements observed were not sufficient enough to re-categorise them as having 'normal' head posture for their age-group[244]. The improvements in head posture appeared independent of upper back and shoulder posture which did not change significantly over the same time period. Whilst these findings do not support the notion that posture of the head, upper back and shoulder are related in this instance[281], we also acknowledge that owing to the small sample size, we may have been unable to detect the relationships.

Finally, it was unexpected that there would be so few musculoskeletal tissues in the upper back that improved in sensitivity following reduction mammoplasty. With good grounding in theory[27], the sensitivity of the tissues examined was anticipated to improve by decreasing the biomechanical loads of large breasts[27]. Levator scapulae and the lower fibres of trapezius were the only tissues to show a significant improvement in sensitivity. It is unclear why these tissues changed when others didn't, but it may be that reducing breast size preferentially decreases the mechanical load on these particular muscles. Further exploration of PPTs in a larger sample of women undergoing reduction mammoplasty could help corroborate this.

In summary, the major limitation of this work was the small size of the surgical sample. It is possible that this made it difficult for us to detect significant or clinically meaningful changes in characteristics. The work has however, provided the first comprehensive and collective assessment of both self-report and physical changes occurring following reduction mammoplasty.

In conclusion, the work of this chapter has highlighted positive effects of reduction mammoplasty. The improvements conferred by this surgery appear to be most clearly reflected in the self-report accounts of women. The measured physical characteristics that were assumed to be related to breast size did not change in ways that were expected. It may be that the physical characteristics take longer to change postoperatively or that the magnitude of change was not detectable in our small sample. Whilst evidence of physical characteristics that change following reduction mammoplasty could help explain the physical

basis for large breasts causing the burden that they do, and provide merit to the procedure of reducing breast size, the results of this chapter highlight that changes in physical characteristics, other than breast size itself, are simply not required for symptoms such as UBP, to be alleviated. Women with large breasts may have physical characteristics that are abnormal or unfavorable but it seems unnecessary for these to be the focus of attention when they do not change by amounts or rates that reflect the improvement in symptoms such as UBP.

Chapter 13 Thesis summary and main findings

13.1 Introduction

Identifying and addressing risk factors associated with musculoskeletal conditions such as UBP is a key priority in the national strategy to promote the healthy ageing of women in Australia[7]. Upper back pain has been studied less frequently than low back or neck pain, yet estimates of the prevalence of UBP, albeit highly variable, suggest that it is a common complaint affecting mature-aged women in particular[1, 4]. The desire to understand factors that make UBP more likely, or more severe, in mature-aged women provided the grounding for this doctoral research. This is important because mature-aged women represent a rapidly expanding proportion of the general Australian population[6].

Prior to undertaking the work of this thesis, the assumption that larger breast sizes increase the risk and severity of UBP had been popularly recirculated without challenge and without objective substantiation. Mature-aged women, who experience an increase in breast size[28] and a change in upper back and torso mechanics[10-12] with age, were considered to be at greater risk of UBP as a result of their breast size[23, 24, 56]. This had not however, been confirmed with quantitative research specifically involving mature-aged women.

In some women with hypertrophic breasts, the burden of increased breast size extended beyond UBP to also affect aspects of health and psychological wellbeing[25, 40, 43, 46, 71, 73-75, 77, 78]. Negative relationships between breast size and aspects of health and psychological wellbeing have, however, had limited exploration in women across a broad range of breast sizes. In addition, no quantitative research had examined the wider implications of having larger breasts on health and psychological wellbeing of mature-aged women, despite these women describing negative feelings towards increasing breast size with ageing[28].

Aspects of health and psychological wellbeing had also had limited examination in the context of UBP. The role of non-physical characteristics, such perceptions of health and psychological wellbeing, in contributing to, or being influenced by, the experience of UBP had received little attention. The biopsychosocial nature of musculoskeletal pain conditions whilst being well-recognised[130], was not well-established for UBP[2].

Upper back pain remains a condition with an uncertain aetiology. Physical characteristics contributing to making the condition more likely and more severe are not clearly defined. Breast size is one of a number of physical characteristics that, changing with age, had been reported to have an uncertain relationship with UBP in mature-aged women.

Putative biomechanical mechanisms proposed in theories of a physical basis for UBP in women with large breasts, provided reasonable rationale for physical characteristics of women with large breasts to explain the presence UBP[27]. These theories, however, had been insufficiently examined using quantitative research. Although some physical characteristics had been reported to vary across women of different breast sizes[22, 23, 53, 55], it was not certain how these differences related to UBP.

The various ways in which breast size and other physical characteristics had been measured and categorised added ambiguity to research. Breast size did not have consistent relationships with other physical characteristics. This inconsistency was evident, even with thoracic kyphosis[22-24, 53], a central tenent of the biomechanical theories explaining UBP in women with large breasts. There was insufficient evidence showing the interplay of breast size with other physical characteristics, and no specific research of mature-aged women that supported speculation that they were more vulnerable to the physical burden of larger breasts[23, 24, 56].

The explanation for UBP in women with large breasts has been particularly understudied. With a predominant focus on a physical basis for UBP, there had been no reason to question that symptoms arose from the strain placed on musculoskeletal tissues as a result of the postural adaptations to large breasts[27]. There had, however, been little formal examination of musculoskeletal tissues across women of different breast sizes to support their involvement in the symptom pathway.

Finally, studies of women undergoing reduction mammoplasty had clearly identified UBP as a symptom leading to surgery[25, 26, 42, 43, 70]. In addition to UBP, it was reported that women prior to surgery experienced a range of negative physical and psychological symptoms related to their breast size[25, 40, 43, 46, 71, 73-75, 77, 78]. The relief of symptoms following reduction mammoplasty were well described[25, 40-42, 69, 70, 76, 196] and demonstrated the functional utility of the surgery. Nevertheless, for UBP, it was not clear why or how improvements occurred. Although an array of health and psychological wellbeing characteristics improved following surgery, these had uncertain relationships with UBP. In addition, the physical characteristics that changed alongside UBP following reduction mammoplasty had received little attention.

The broad aim of this thesis was therefore to investigate the relationship between breast size and UBP in mature-aged women. This chapter discusses the findings generated from this doctoral research project by answering the thesis research questions posed at the start (summarised in Figure 13.1), whilst also outlining the strengths and weaknesses of the methods used and the overall implications of the research. A summary of the work undertaken on specific measurement procedures is also presented.

|	
1	**Are larger breast sizes associated with UBP in mature-aged women?** • Yes, for each increment in BSS, women are 13% more likely to have UBP. • Chapter 6 highlights the direction and strength of the association between breast size and UBP.
2	**Are there aspects of health and psychological wellbeing, currently considered a health burden, that are associated with breast size in mature-aged women?** • Yes, larger breast sizes are negatively associated with breast-related physical wellbeing, breast satisfaction and body satisfaction. • Chapter 6 highlights larger breast sizes, independent of potential covariates age BMI and menopausal status, have implications for health and psychological wellbeing in a broader population of mature-aged women beyond those seeking reduction mammoplasty.
3	**What aspects of health and psychological wellbeing associated with UBP are independent of breast size in mature-aged women?** • Breast satisfaction and SF-36 PCS scores are associated negatively with both the presence and severity of UBP. • Chapter 7 highlights the multidimensional nature of UBP and characteristics unrelated to breast size that are relevant to the experience of UBP.
4	**What is the importance of breast size relative to other physical characteristics in increasing the likelihood and severity of UBP in postmenopausal women?** • Independently, breast size is less important than age, height, lean mass and upper back extensor muscle endurance in accounting for the risk and severity of UBP. • The significance of the relationship between breast size and UBP is weakened by considering other associated physical risk factors. • Chapter 8 adds perspective to the long-standing assumption that larger breasts inevitably lead to the presence and greater severities of UBP and draws attention to the putative protective role of upper back extensor muscle endurance.
5	**What physical characteristics related to breast size support a physical basis for UBP in postmenopausal women with larger breasts?** • Thoracic kyphosis is not related to either breast size or UBP, and posture is weakly related to breast size but has no relationship with UBP. • Upper back extensor muscle endurance is associated with breast size and the presence and severity of UBP. • Breast size is associated with prevalent vertebral fractures but UBP has uncertain relationship with vertebral fractures. • UBP is related to greater sensitivity in selected upper back musculoskeletal tissues whereas breast size is not. • Chapters 9-11 highlight evidence that supports upper back extensor muscle endurance and vertebral fractures as characteristics that may be relevant to theories of a physical basis for UBP in women with large breasts.
6	**Which characteristics, relevant to UBP, that change following reduction mammoplasty, progress understanding of the relationship between breast size and UBP?** • Upper back pain showed a quick and clinically meaningful improvement following reduction mammoplasty. • Breast satisfaction and SF-36 PCS scores improved quickly and by clinically-meaningful amounts, whereas upper back extensor endurance improved quickly, but only by small amounts that may have been influenced by a ceiling effect. • A higher prevalence of vertebral fractures were noted in women seeking reduction mammoplasty compared to cross-sectional samples of women of similar age. • Chapter 12 highlights evidence that builds on the cross-sectional findings of chapters 6-11, showing that breast satisfaction, SF-36 PCS scores and upper back extensor muscle endurance are characteristics that may be relevant to explaining the relationship between breast size and UBP. In an extension of existing theories, the roles of upper back extensor muscle endurance and vertebral fractures in the clinical picture of UBP in women with large breasts are suggested but not proven by the cross-sectional and prospective work of this thesis.

Figure 13.1 Thesis research questions and summary of responses

13.2 Measurement tool investigations

In order to ensure the reliability and suitability of measurements used in this thesis, two reliability studies and one validation study were completed.

The preliminary work of this thesis conducted across two studies and presented in Chapter 3 and Chapter 4, investigated the processes of measuring posture, upper back mobility, upper back musculoskeletal tissue sensitivity, and breast size. This work had multiple purposes. First, to assist with the development of the main protocol, methodological steps in measuring posture and breast size were trialed. It was determined that the measurement of posture using photogrammetry was best done with participants in standing and that the BSS method was a more suitable way of measuring breast size than estimating volumes using the anthropometric method. Second, to establish if reliable measurements could be made by the thesis candidate using the selected tools, repeated measures of posture, upper back mobility, upper back musculoskeletal tissue sensitivity, and under and over-bust circumferences were examined. It was determined that measurements could be made reliably. This was important in informing the successful design and execution of the repeated measures study of the main project (Chapter 12). Finally, the preliminary work of the project served to provide familiarisation with participant recruitment, measurement equipment, procedural steps and data management. This allowed any difficulties to be identified and ascertained the feasibility of capturing data on the selected physical characteristics by safe and effective means.

A strength of the preliminary work included that it recruited participants from the same study population that was to be used for the main project. This allowed good judgment on the feasibility of using the proposed methods with this population of women. There were no safety concerns with the procedures and participants coped well with following instructions and tolerated the demands of each measure. Another strength of this preliminary work was the size of the pilot sample. A sample of 20 participants allowed good judgment to be made on the suitability of measurement methods and was adequate for estimating intra-rater reliability of selected measures. Samples of equivalent size have been employed in previous reliability studies of posture using photographic methods[257] and tissue sensitivity using digital algometry[250].

The limitations of the preliminary work of the project included that it only examined those measurement procedures deemed to be potentially influenced by the skill of the thesis candidate in obtaining reliable measurements. Conclusions on the feasibility and tolerability of procedures were limited to the methods that were trialed. Although the preliminary work

did not test the feasibility of all physical measures that were planned in the main project with the pilot sample, the protocol was practiced in its entirety in self-directed study. This provided some confidence that the measures could be completed in a timely and organised manner. Overall, the preliminary work of the project provided confidence in the measurement tools used in this doctoral research for evaluating posture, upper back mobility, upper back musculoskeletal tissue sensitivity, and breast size.

The validity of thoracic kyphosis measures, investigated in Chapter 5, highlighted the usefulness and limitations of radiological and non-radiological methods. As a central tenent in biomechanical theories for breast-related UBP, thoracic kyphosis was a variable of particular interest in the project. The accurate measurement of thoracic kyphosis was imperative to drawing confident conclusions on its relationship with breast size. Research on the relationship between breast size and thoracic kyphosis had yielded conflicting results in the past. The use of different measurement methods for thoracic kyphosis seemed to have contributed to these contradictory findings.

While the radiographic Cobb method for assessing thoracic kyphosis was widely-acknowledged as the gold standard, elements of this method had the potential to be affected by the participant characteristics (age, presence of degenerative pathology)[236, 301]. This was particularly relevant considering the study population being examined in this project. The vertebral centroid method was an alternative radiographic technique that generated a thoracic kyphosis angle that addressed these concerns[236]. Using radiographic methods in the project assured the robust measurement of thoracic kyphosis, while also allowing comparisons to prior research using this gold standard technique. This was important in being able to contribute meaningfully to the body of research on this topic.

At the outset of the project Flexicurve had reasonable evidence for being a reliable measure of thoracic kyphosis[59-64]. The validity of Flexicurve was, however, in some doubt after a lack of agreement between Flexicurve and radiographic Cobb angles was reported in several studies[59, 61, 64, 237]. The validity study in this thesis[255a] (Chapter 5) confirmed that Flexicurve did not deliver accurate estimates of thoracic kyphosis in our postmenopausal subset. This meant that Flexicurve could not be used by us as a surrogate measurement tool where radiographic measures of thoracic kyphosis had not been completed (n=2). While this work also showed for the first time that Flexicurve showed better agreement with radiographic vertebral centroid angles than with Cobb angles, the large systematic errors that were evident indicated that Flexicurve would not be recommended where accurate measures of thoracic kyphosis were required. Instead, it is suggested that Flexicurve is likely to be useful in providing a simple, non-invasive method for recording the progression of thoracic kyphosis

in clinical settings, where the goal may be to assess change over time rather than an determine actual measurement.

13.3 Thesis research question 1. Are larger breast sizes associated with upper back pain in mature-aged women?

The first research question of the thesis was addressed in Chapter 6, an exploratory cross-sectional study of 269 mature-aged women (aged ≥40 years) that examined the relationship between breast size and aspects of health and psychological wellbeing[255b]. Upper back pain was a key variable of interest in this study. The results presented in this chapter reflect previous literature[22-24] to confirm that breast size is indeed related to UBP. The relationship between breast size and UBP, however, was not strong, with breast size explaining less than 9% of the total variance in UBP. This supports previous work by Coltman et al[267] who reported breast size (volume) was one of three factors (breast volume, age, breast splay) that together, accounted for only 23% of the variance in upper torso musculoskeletal pain in women aged 18-82 years. This variance suggests that other factors contribute to explaining upper torso musculoskeletal pain. Similarly, our specific investigation of UBP highlights that it is also likely that there are factors other than breast size that are important for UBP in mature-aged women.

Of significance in this chapter though was that, for the first time, the increased likelihood of UBP associated with breast size, estimated from bra sizes, was calculated to be 13% for each one-size increase in band or cup size. One in five women are reported to experience an increase in breast size after menopause[29], although it is not certain by how much breasts increase in size following menopause[29] or with ageing[28]. The association identified in our work is noteworthy when a typical increase in bra size by one cup size *and* one band size (e.g.12C to 14D), results in a 26% greater likelihood of UBP.

An important aspect of the work presented in Chapter 6 was that the role of breast size in determining UBP was evaluated in the context of the potential covariates age, BMI and menopausal status. In contrast to findings in low back pain research[302], the findings of Chapter 6 did not identify BMI as a significant independent predictor of UBP in mature-aged women. Age was reported with breast size to explain the small total variance (9%) in UBP but increasing age was associated with lower odds for UBP. It was unexpected but not unprecedented that older participants in the community-based sample were less likely to report UBP as similar findings have been noted in previous studies of back pain[267, 303, 304]. In Chapter 8, where this trend was also reported in the postmenopausal subset, we alluded to a possible reason for this being a change in pain perception with age[305].

13.3.1 Methodological considerations

In view of the cross-sectional study design, it is acknowledged that information on breast size and UBP were collected at a single time point, and extraneous variables, for which there were no control, may have influenced the reporting of UBP at that time. The work is also limited in determining causation. The temporal association between larger breast size and UBP cannot be inferred from the results.

The sample size was sufficient to be confident in the results that have been presented. Although there is limited data available on the prevalence of UBP in adult populations, the point prevalence of UBP in the community-based sample of 61% appeared comparable to previous estimates[2]. Upper back pain is noted to be more prevalent in females[2-5] and this high prevalence was therefore not an unexpected finding in our study. Also adding confidence in the results of this cross-sectional work, was the heterogeneity of breast sizes represented within the community-based sample. Because the sample included women with a broad range of breast sizes, it provides confidence that the sample was a reasonable representation of mature-aged women in general.

Whilst the use of a self-report measure of breast size in contrast to measuring breast size objectively, was an identified limitation of the work in Chapter 6, this may not have been a substantial limitation. It is frequently stated that bra sizes can be inaccurately-reported by women for a variety of reasons that includes them wearing and therefore reporting an incorrectly-fitted and sized bra[140, 141, 143]. The preliminary work of Chapter 4 showed a strong correlation ($r>0.76$) between self-reported and measured bra sizes when these were converted into the ordinal BSS. This suggested that these measures of breast size (bra size) were at least comparable. With this is mind, it remained plausible that in mature-aged women at least, the inaccuracies of self-reported bra sizes may not be as significant as previous work has suggested. The validity of using bra sizes to infer breast size has had limited investigation in large samples of women and will remain difficult to determine in the absence of a gold standard breast size measure against which to judge them. The BSS, in contrast to the bra cup size alone, at least considers the differences in cup sizes across different band sizes[156, 157]. The BSS provided a reasonable representation of breast size and allowed us to rank participants breast sizes. It's precision as a measurement tool, and validity in estimating actual breast size, were acknowledged limitations of the method.

13.3.2 Clinical and research implications of thesis research question 1

The finding that larger breasts increase the likelihood of UBP in mature-aged women aligns with our expectation. For clinicians working with mature-aged women presenting with UBP

who may not have previously considered breast size as an associated factor, this work brings clarification on not only the direction but also the strength of the relationship between breast size and UBP. While UBP is more likely in women with larger breasts, how bothersome this UBP is to them needs further clarification. Future research may consider investigating this together with other aspects of the UBP such as how frequently it is experienced. By considering the role of potential covariates, UBP is presented here as a condition that is more strongly associated with breast size than with BMI based on self-reported anthropometric data. As breast size has been found to explain only a small proportion of the variance in UBP however, future research may look to confirm the strength of association with UBP relative to BMI using objective measures.

13.3.3 Summary

In answer to the first research question of the thesis, larger breast sizes are associated with UBP. This illustrates one way that larger breasts negatively associate with the health of mature-aged women.

13.4 Thesis research question 2. Are there aspects of health and psychological wellbeing, currently considered a health burden, that are associated with breast size in mature-aged women?

The cross-sectional study in Chapter 6 also informed the second research question of the thesis by describing, for the first time, some of the negative relationships between breast size and aspects of health and psychological wellbeing[255b]. Specific relationships of importance were between breast size and breast-related physical wellbeing, breast satisfaction and body satisfaction. These relationships were recorded using BREAST-Q and a NRS and had only been previously reported in women with hypertrophic or macromastic breasts seeking reduction mammoplasty.

Breast-related physical wellbeing, body satisfaction and breast satisfaction, all of which have been observed to be at low levels in women prior to reduction mammoplasty[46, 70, 74-76, 78, 172, 196], were negatively associated with increasing breast size in our community-based sample of mature-aged women. This indicates that negative relationships between breast size and aspects of health and psychological wellbeing may not be exclusive to only those women seeking reduction mammoplasty.

Normative data that were available for comparison using the BREAST-Q tool showed that our sample had roughly average levels of breast satisfaction (mean score of 53 compared with norms of 57, n=1205) but lower than average breast-related physical wellbeing (mean

score of 68 compared with norms of 76)[163]. The community-based sample was reasonably comparable to this normative sample in terms of age (mean age of 58 years compared with normative sample mean age of 55 years) but may have differed on the basis of UBP. Half of the normative sample reportedly had a chronic health condition, however, pain was not one of the commonly-cited conditions[163]. Pain is a central theme of the subscale for breast-related physical wellbeing on BREAST-Q (Appendix 4c). As the majority (61%) of our community-based sample reported UBP, this may explain why our sample had lower than average levels of breast-related physical wellbeing.

It was of interest that we were not able to confirm an independent association between breast size and HRQoL measured using the SF-36 tool. In comparison to published normative data for Australian women of middle (45-49 years, n=14200) and older (70-74 years, n=12566) age[176], the community-based sample showed overall slightly lower than average SF-36 PCS scores (mean score of 47 compared with norms of 50 (middle-aged) and 51 (older-aged)), and roughly average SF-36 MCS scores (mean score of 51 compared with norms of 47 (middle-aged) and 51 (older-aged)). On balance the community-based sample therefore appeared to be representative of middle-age and older women in the general Australian population. Incidentally, both SF-36 summary scores (PCS and MCS) were approximately 5-points higher in our community-based sample than those reported preoperatively for women with macromastic breasts seeking reduction mammoplasty[70, 74, 172]. Whilst the results of Chapter 6 do not indicate that breast size is independently associated with SF-36 PCS or MCS scores in multivariable models, the results have highlighted the relevance of BMI and age to these respective scores. Our data suggest that differences in BMI and age may explain more variance than breast size in HRQoL.

Another finding of particular interest was that BMI, rather than breast size, was statistically foremost in explaining differences in physical activity levels amongst our community-based sample. This provided further perspective on the relationship between breast size and physical activity levels. While our correlational findings complemented prior research[139] by indicating that women with larger breasts were typically less physically active, by examining potential covariates, our work was unable to confirm that breast size was significantly associated with physical activity levels after accounting for differences in age and BMI. Our results suggest that the relationship between BMI and physical activity, in particular, is stronger than that between breast size and physical activity. By not controlling for BMI as a potential confounder, the differences in physical activity levels noted previously between women of different breast sizes[139] may be questionable. It is also possible that the use of different methods used to assess physical activity has contributed to seemingly contradictory

outcomes in research on this topic. Different aspects of physical activity measured over different time frames are factors reported to contribute to poor agreement between physical activity measures[306, 307]. The information collected by different physical activity measures is often heterogeneous and can lack sufficient detail on activities that may be important in the context of particular conditions. A limitation of the HAP noticed from our work was that it didn't capture why someone had stopped doing an activity, leaving us to speculate that breast size was an influential factor. In addition, reporting accuracy is particularly problematic when measuring physical activity[167], especially for measures where participants are estimating actual time spent being physically active. With these limitations in mind, caution is suggested when interpreting the relationship between physical activity and variables of interest in isolation.

13.4.1 Methodological considerations

In addition to those highlighted in reference to research question 1, there are limitations of cross-sectional research that do not allow causation to be inferred. However, the findings in relation to this thesis research question provide evidence that increased breast size could be problematic for the health and psychological wellbeing of a wider female population and not limited to those who are seeking reduction mammoplasty.

13.4.2 Clinical and research implications of thesis research question 2

An important implication of the work of Chapter 6 was that it evaluated the relationships between breast size and aspects of health and psychological wellbeing in the context of the potential covariates age, BMI and menopausal status. Breast size had a stronger association than age with breast-related physical wellbeing and breast satisfaction. It also had a stronger relationship than BMI with body satisfaction. The findings support our expectations. However, since breast size only had identifiable relationships with some, but not all, of the aspects of health and psychological wellbeing examined, our expectation is only partially supported. Whilst it was anticipated that breast size would have independent relationships with more variables, the work of this chapter highlights the important influential effects of interacting covariates. By controlling for covariates in this exploratory work, we have gained a more precise estimate of breast size as a characteristic associated with aspects of health and psychological wellbeing.

These findings help to raise the awareness of clinicians working with mature-aged women who may not have previously considered how larger breast sizes relate to health and psychological wellbeing. The significant independent relationships that breast size has with breast-related physical wellbeing, and body and breast satisfaction, provides impetus for

further research to investigate modifiable factors related to breast size that may play a role in improving these aspects of health and psychological wellbeing. Factors that influence how embarrassed a woman is by her breasts and how satisfied she is with her bra fit may be pertinent avenues for future investigation. These variables were clearly related to increasing breast size in the findings of Chapter 6, but little is known about the reasons for this or the implications of targeting their improvement using conservative measures.

13.4.3 Summary

In answer to the second research question of the thesis, there are multiple aspects of psychological wellbeing that are negatively associated with breast size in mature-aged women. Those that have been identified in this work include the characteristics of breast-related physical wellbeing, body satisfaction and breast satisfaction.

13.5 Thesis research question 3. What aspects of health and psychological wellbeing associated with upper back pain are independent of breast size in mature-aged women?

To answer the third research question of the thesis the cross-sectional data of the community-based sample used in Chapter 6 and presented in Chapter 7, identified SF-36 PCS scores and breast satisfaction as aspects of health and psychological wellbeing that were associated with the presence and severity of UBP independent of breast size.

These findings build on those of Chapter 6 where exploratory work defined aspects of health and psychological wellbeing related to breast size. It was clear from Chapter 6 that women with larger breasts were more likely to report the presence of UBP. Additionally, there were a number of other negative health and psychological wellbeing characteristics manifested in women with larger breasts. Since cross-sectional data are limited in determining cause and effect, it is possible that what had been identified as potential health implications of having larger breasts may also reflect a burden attributable to having UBP. To clarify this, UBP needed further exploration, providing the rationale for Chapter 7.

In the absence of relevant prior work showing how the burden of UBP may manifest, the results of Chapter 7 were discussed in the context of what had been reported in low back and neck pain research. This is because in much larger bodies of work, the burdens of pain have been better established. Chapter 7 highlighted a negative relationship between UBP and HRQoL. This appeared somewhat consistent with findings from low back pain research, where large cross-sectional studies have previously reported lower HRQoL scores for community-dwelling older adults (aged ≥ 65 years) with low back pain recalled over a

similar period (within the previous month)[136, 137]. Comparable to chronic back and neck pain reported by adults of varied age (18-98 years)[135], UBP reported by our community-based sample was more clearly related to HRQoL through the SF-36 PCS scores. Lower SF-36 PCS scores for people with low back and neck pain, in a large population study (n=17249) where comorbidities were controlled effectively[135], provided a good basis for confirming what was found in Chapter 7, where lower SF-36 PCS scores were recorded for participants with UBP and those reporting greater severities of UBP. This suggests that, consistent with the propositions from low back and neck pain research[135-137], UBP is more strongly related to the physical function components of HRQoL.

It was of interest that breast satisfaction was the only other aspect of health and psychological wellbeing associated with UBP following the multivariable analysis in Chapter 7. There are previous reports linking breast dissatisfaction in adult women of varied age to lower body satisfaction[34], psychological distress[35], and to the motivation to seek reduction mammoplasty[43]. Breast satisfaction has not, however, been previously examined in relation to UBP or any other musculoskeletal complaint. In Chapter 7 the likely complex nature of the relationship between UBP and breast satisfaction is raised. Whilst it is not clear how this relationship can be explained, it is possible that women who attribute their UBP to their breasts may, as a result of this, be less satisfied with their breasts.

13.5.1 Methodological considerations

The reciprocal nature of relationships that are possible between UBP and self-reported aspects of health and wellbeing provided a challenge to interpreting the findings of Chapter 7. A strength of the approach taken in this chapter was that it considered how aspects of health and psychological wellbeing may be related to UBP by cause and by consequence and, since the cross-sectional nature of the data did not permit conclusions either way, it was important to appreciate that relationships could be bidirectional.

A limitation of the work presented in Chapter 7 was that the subscales of SF-36 tool were not analysed to help explain which components of HRQoL were most strongly associated with UBP and why UBP was related to SF-36 PCS scores but not to SF-36 MCS scores. Where subscales of the SF-36 have been previously examined in relation to chronic back and neck pain, it has been clearly shown that subscale scores of the SF-36 which differ by the greatest amounts between pain and nil-pain groups are: physical functioning, role limited by physical problems, general health and, unsurprisingly, bodily pain[135]. These are all subscales that are weighted more strongly for calculating SF-36 PCS scores[133] and are typically affected by a range of musculoskeletal diseases[308]. Whilst it cannot be confirmed, it seems likely that UBP

has a similar relationship with HRQoL to other musculoskeletal conditions where pain is thought to lead to functional impairments[137, 308].

13.5.2 Clinical and research and implications of thesis research question 3

By identifying that SF-36 PCS scores and breast satisfaction are associated with UBP independent of breast size, the expected outcome for this research question is supported. At the outset of this doctoral research project it was not certain which aspects of health and psychological wellbeing would associate most strongly with UBP. It was expected however, that UBP would have important relationships with non-physical characteristics given the biopsychosocial nature of musculoskeletal pain conditions[309].

These doctoral findings, for the first time, shed light on the multidimensional nature of UBP by showing that characteristics other than those that are physical in nature, are important to the experience of UBP. This information advances our understanding of UBP as a musculoskeletal pain condition and supports speculation that psychosocial, behavioural and lifestyle factors play an influential role[2]. The finding that HRQoL and breast satisfaction are associated with UBP encourages future clinical attention to be given to these factors.

The relationship between UBP and SF-36 PCS scores looks more likely to represent the wider implications of UBP as a musculoskeletal pain condition in mature-aged women. This perhaps confirms what many clinicians have previously noted, from clinical observations and anecdotal accounts, that pain can reduce physical function and that reducing function affects one's sense of physical wellbeing. These findings provide a basis for monitoring physical function in mature-age women presenting clinically with UBP in an effort to lessen the burden attributable to it.

The relationship that has been identified between UBP and breast satisfaction demonstrates, in another way, the multidimensional nature of UBP. Whilst the basis for this relationship is not certain, these findings build on those of Chapter 6 by identifying that lower breast satisfaction in mature-aged women, in addition to being related to having larger breasts, is also related to the presence and severity of UBP. For clinicians and researchers, this indicates that it may be just as important to consider how a woman feels about her breasts as it is to consider the size of her breasts when exploring factors related to her UBP.

For researchers, the work of Chapter 7 clearly illustrates the complexity of understanding UBP. Having acknowledged that there are aspects of health and psychological wellbeing that are associated with UBP whilst controlling for larger breast size, future research on breast-

related themes may need to carefully consider what are viewed as consequences of large breasts and what are factors related to UBP.

13.5.3 Summary

In answer to research question 3 of the thesis, aspects of health and psychological wellbeing that, independent of breast size, are associated with UBP in mature-aged women include SF-36 PCS scores and breast satisfaction. By way of negative association with both the presence and severity of UBP, these are identified as two characteristics worth considering clinically when managing mature-aged women with UBP.

13.6 Thesis research question 4. What is the importance of breast size relative to other physical characteristics in increasing the likelihood and severity of upper back pain in postmenopausal women?

Addressing the fourth research question of the thesis, the main aim of Chapter 8 was to determine if breast size was associated with the presence and severity of UBP relative to other physical characteristics. This was undertaken to add to the findings of Chapter 6, and to confirm breast size as an associated risk factor. Assessing breast size with greater objectivity was a key element to answering this thesis research question. Establishing the physical characteristics associated with UBP was also undertaken to build on the findings of Chapter 7 where a substantial proportion of the variance in UBP presence and severity remained unexplained by SF-36 PCS scores and breast satisfaction.

In Chapter 8, a cross-sectional study of a subset of the sample used in Chapters 6 and 7 was conducted. One hundred and nineteen postmenopausal women, with and without UBP, were sequentially recruited from the community-based sample in order to determine the physical characteristics of postmenopausal women that were associated with the presence and severity of UBP. The decision to refine the sample to postmenopausal women only was in an effort to eliminate the potential influence of menopausal symptoms on the characteristics being measured.

The results of our UBP study[256a] (Chapter 8) confirmed that breast size had a weaker association with the presence and severity of UBP compared to other physical characteristics in postmenopausal women. Age, height, lean mass, and upper back extensor muscle endurance were those physical characteristics with stronger relationships than breast size to UBP. Breast size did, however, have a more important association with the presence and

severity of UBP than other measured characteristics such as thoracic kyphosis, BMD and posture. As a result, breast size was included in the multivariable model for UBP but, as an associated characteristic, was not significant in multivariable analyses. These findings indicate that breast size is less important as an associated risk factor for UBP when considered amongst other physical characteristics.

From the accumulating evidence of Chapters 6 and 8, the relationship between breast size and UBP has been shown to be consistent, but not always strong or significant when other factors are considered. It is possible therefore, that the UBP related to breast size is mediated by other factors or that breast size is just a small contributor for some women. This raises the possibility that there could be characteristics in some women that offset UBP irrespective of their larger breast size. Our UBP study[256a] (Chapter 8) identified upper back extensor muscle endurance as a physical characteristic with a positive relationship with the presence and severity of UBP that may potentially fulfill this function.

Causative relationships between the variables measured in the cross-sectional work of this project cannot be assumed. It is not known, for example, whether reduced upper back extensor muscle endurance existed prior to and therefore predisposed participants to UBP or that reduced upper back extensor endurance was a result of UBP in our participants. There are, however, trends[117] and biomechanical theories[310] in low back pain research that lends weight to the proposition that having back extensor muscles with better endurance could offset the likelihood and severity of back pain. Back extensor muscles with better endurance that provide the spine with better stability create less loading on intervertebral joints[311] and lower resulting skeletal and ligamentous strain[310]. Whilst these relationships remain largely theoretical, they may provide some understanding of how upper back extensor muscle endurance may fit as a protective factor into the clinical picture of UBP.

Compared to a relatively small normative dataset (n=276)[115], the mean (SD) upper back extensor muscle endurance times (81.8 (3.2)s) of participants of our postmenopausal subset with UBP (mean (SD) age 59 (7) years), placed them below the 50th percentile for women aged 50-59 but above the 75th percentile for women aged over 60 years. The limitation of this comparative normative dataset was that the number of participants in each age-group was not clear, making it difficult to know how representative the data were for comparison. The data presented by Ito et al[230] who employed the isometric chest raise test in a similar manner to examine women with and without low back pain (n=60), provides further perspective on the meaning of our data. They showed mean (SD) endurance times (70.1 (51.8)s) in younger women (aged 35 to 49 years) with chronic low back pain that were

comparable to our participants with UBP. This consistency in findings adds some confidence in our results.

A noteworthy point from comparing our data with others was that our postmenopausal subset overall, with a mean age of 61 years, looked to have above average upper back extensor endurance for their age[115] and equivalent back extensor endurance to women who, on average, were 15 years younger[230]. This suggests that our sample overall, may have been fitter than average. This could have been an additional factor to those cited in our UBP study[256a] (Chapter 8) that could explain why women with UBP in the postmenopausal subset differed from women without UBP on the basis of so few physical characteristics. This may also have had implications for identifying the relationship between breast size and UBP, discussed later in section 13.7.

13.6.1 Methodological considerations

Since no prior study had collectively examined multiple physical characteristics in relation to UBP, a strength of the approach taken in Chapter 8 was that it allowed physical characteristics to be compared and ranked in terms of their importance to the presence and severity of UBP in postmenopausal women. Another strength was in the use of a more specific definition of UBP which allowed odds to be identified more specifically for UBP. This was particularly important in the context of breast size, where previous studies[23, 267] had not exclusively assessed pain in this region. The UBP measure used in our study, whilst effectively capturing the presence and severity of UBP did, however, have some limitations. The first of these was that it only captured those participants with UBP over the previous month. The recall period chosen for use in this study was based on prior research examining the prevalence of thoracic spine pain[2] and low back pain[149]. Consideration was given to using a longer recall period but the possibility of overestimating the prevalence of UBP in our population deterred this. Another limitation of the UBP measure included that it did not capture how frequently pain was felt within this region. This means that we don't know whether the UBP that participants had felt within the past month was a frequent or infrequent occurrence for them. Other pain-related information not captured in our study of UBP but that may have provided additional insight into the UBP experience were pain-provoking activities (aggravating factors), pain-alleviating strategies (easing factors) and overall irritability of symptoms. Future work may consider exploring the UBP experience in more depth to overcome these limitations.

With regards to the relationship determined between breast size and UBP, confidence in the results of Chapter 8 was added by using measured bra size as a more robust and objective

evaluation of breast size. Chapter 8 aligned with results from Chapter 6 that used self-reported bra sizes, that as an isolated characteristic, breast size was significantly associated with increasing the likelihood of UBP. Further information added by Chapter 8, however, was that beyond the likelihood of UBP, breast size was also related significantly with the severity of UBP. The significance of the relationship between breast size and UBP was, however, weakened by considering other associated physical risk factors which still limits us from intimating how bothersome larger breasts are for women in terms of UBP.

In addition to those highlighted for the cross-sectional work of thesis research questions 1 to 3, there were some limitations of the data used to answer thesis research question 4. The isometric chest raise test used for assessing upper back extensor muscle endurance was selected because it was easy to administer, had previously been used with older women[312] and people with back pain[230], and normative data were available for comparison[115]. The test was modified from its original version[115, 230] to allow women with larger breasts to complete the test without disadvantage, and also to help position participants so that they would not be impeded if their extension mobility, beyond neutral, was poor. By using a wedge cushion instead of a flat cushion it is not certain that the demands of the test were the same as those described in its original format[230]. It is also not clear if the test adequately isolated upper back muscle activity and didn't also engage lower back extensor muscles. The positioning of participants was carefully considered and securing straps may have helped to promote upper back muscle activity[256a], but how effective these were is uncertain. Finally, the reasons for participants ending their test were not recorded but this could have helped to better understand the results by identifying those who ended because of fatigue versus those who ended for other reasons (e.g. pain, boredom). As an assessment of endurance, the isometric chest raise test may have been particularly influenced by the attitude and resilience of participants. For those participants with UBP, the test may have become more a test of their ability to resists the body's natural predisposition to stop doing something that hurts, than it was a test of muscle endurance and this needs consideration.

13.6.2 Clinical and research implications of thesis research question 4

Whilst the relationship between breast size and UBP is not inconsequential, the findings of Chapter 8 show it is weaker than relationships between UBP and other physical characteristics in postmenopausal women. This was an unexpected finding. It seemed reasonable to anticipate that breast size would be as strong a risk factor for UBP as any other physical characteristic, particularly when there was a plausible theory stating a physical basis for breast-related UBP[27]. In a large study (n=300), it was reported that women differ in their reporting of upper torso musculoskeletal pain according to their breast size[22]. It was

anticipated that by examining UBP specifically, rather than pain across seven different upper torso regions, that the relationship we would find between breast size and UBP would be stronger than had been previously reported between breast size and upper torso musculoskeletal pain[267]. Had univariate analysis of the relationship between breast size and UBP been used to draw conclusions, our work would have aligned with existing theories. However, since UBP was a condition that was anticipated to have multiple possible associated risk factors it seemed intuitive to analyse it as such. What was not considered prior to the project, or alluded to in past theories, but that has become immediately apparent by using multivariable analysis, is the influential effects of other physical characteristics on reducing the strength of the relationship between breast size and UBP. The advance in knowledge that our UBP study[256a] (Chapter 8) brings to existing theories of breast-related UBP is that the relationship between breast size and UBP is not as clear and distinct as theories suggest.

In addition to the finding for breast size, it was unexpected that UBP would be associated with so few physical characteristics. This was particularly so, given the amount of prior research that had described the changes with age in upper torso mechanics in women which suggested an inherent vulnerability to UBP for postmenopausal women. One explanation for our findings, as alluded to in Chapter 8, was the relatively low mean NRS scores for UBP severity in our participants with UBP. This may have been simply a matter of chance based on recruitment strategy where enlisting people with more severe UBP was limited by our exclusion criteria which omitted those with a known pathology of the thoracic spine and those reporting recent or long-term use of pain medication. It is possible that more relationships may have been identified if the mean UBP NRS score was higher. A broader examination of UBP may also have been helpful. As an alternative approach we could have incorporated other information on UBP, such as the frequency and duration of symptoms and incorporated more aspects of UBP into a composite UBP score. This approach, which might be considered in future research, could provide an overall indication of how bothersome UBP is to participants by taking account of other important elements of the condition. Future studies could also actively target a range of UBP levels and consecutively select pain and nil pain participants in a subset that have been stratified for UBP severity.

In adding to the findings of Chapter 6, breast size as an associated risk factor for UBP is clearly less prominent when it is considered alongside other physical characteristic risk factors and this is informative for clinicians and researchers. On the one hand, the findings support that clinical attention may be better given to those physical characteristics with stronger relationships to UBP. It also highlights however, that breast size could be

particularly difficult to prospectively determine as a risk factor for UBP with a relationship that looks to be influenced by other factors.

Perspective is added to the long-standing assumption that larger breasts inevitably lead to the presence and greater severities of UBP. By considering the more complete physical picture of postmenopausal women, our findings cast some doubt over the simplistic and independent role of breast size in determining UBP. The work of Chapter 8 was also unable to confirm that many of the physical characteristics putatively linked with breast size, were important to the clinical picture of UBP. Two physical characteristics that have been frequently cited in biomechanical theories of breast-related UBP, thoracic kyphosis and posture, also appear to have indistinct associations with UBP in postmenopausal women.

The work of Chapter 8 has however shed light on the putative protective nature of upper back extensor muscle endurance that may be relevant to the relationship between breast size and UBP (refer to section 13.7). The protective properties of strong back extensor muscles has been previously acknowledged in postmenopausal women with osteoporosis where greater back extensor strength typically correlates with less thoracic kyphosis[110, 111, 313] and a reduced risk of vertebral fractures[111, 113]. Identifying in this chapter that, for postmenopausal women in general, having better upper back extensor muscle endurance is associated with lower likelihood and severities of UBP has considerable clinical value.

It is clinically appealing to consider that training the strength and endurance of back extensor muscles could have extensive benefits for postmenopausal women. Of note, there is evidence that already demonstrates the benefits to thoracic kyphosis of training back extensor strength over a two-year period in women aged between 49-65 years[312]. The beneficial effects of back extensor strength training on thoracic kyphosis over shorter durations of 8 weeks[314] and 12-weeks[315] have also been demonstrated in women over 65 years-old. Additionally, the long-term reduced risk of vertebral fracture is another benefit seen in healthy postmenopausal women who, eight years after completing a 2-year back extensor training programme, recorded a 2.7 times reduction in vertebral fracture risk[113]. Determining that the likelihood and severity of UBP is reduced by training to improve upper back extensor muscle endurance is an avenue for future research that may add to the long list of benefits of training back muscle function in postmenopausal women. This could give clinicians further reasons to incorporate upper back extensor muscle endurance training into their management of postmenopausal women with UBP.

Building on the findings of Chapter 7, the multifactorial nature of UBP has been further illustrated in Chapter 8, where, in postmenopausal women, a range of physical characteristics

have been identified to be relevant to the clinical picture of UBP. This is also an important advancement in understanding UBP as a musculoskeletal condition.

13.6.3 Summary

In answer to the fourth research question of the thesis, breast size has less importance than other physical characteristics in increasing the likelihood and severity of UBP. Age, height and upper back extensor muscle endurance are physical characteristics that are associated more strongly than breast size with the presence of UBP in postmenopausal women. Collectively though, these other characteristics still only explain less than a third of the variance in the presence of UBP. Age, lean mass and upper back extensor endurance are physical characteristics more strongly associated with the severity of UBP than breast size. However, again, these characteristics each account for only very small changes in UBP severity. It is possible that upper back extensor muscle endurance, has a protective association with UBP.

13.7 Thesis research question 5. What physical characteristics related to breast size support a physical basis for upper back pain in postmenopausal women with larger breasts?

Answering the fifth research question of the thesis required studying the trends in the cross-sectional data of Chapter 8 and Chapter 9, where physical characteristics related to breast size and to UBP were identified, and discussing the trends in the context of a biomechanical theory that links breast size to UBP. Discussions remain theoretical because as previously stated, causal relationships cannot be assumed from cross-sectional data. In addition, this thesis research question encompasses the exploratory work of Chapter 10 and Chapter 11 which identified new relationships between breast size and physical characteristics that have not been previously investigated as part of biomechanical theories. The thesis research question focuses specifically on evidence that theoretically supports a physical basis for UBP and therefore the role of non-physical characteristics (aspects of health and psychological wellbeing), reported in Chapters 6 and 7, are not addressed here.

The first notable finding across Chapters 8 and 9 was that thoracic kyphosis was not related to either breast size or UBP. As the first research to examine the linear relationship between breast size and thoracic kyphosis, it was unexpected that this was neither strong nor statistically significant. The postmenopausal subset provided good heterogeneity in terms of breast size and thoracic kyphosis which suggests that we can be confident in the relationship we have identified in this sample. The basis of a relationship between breast size and

thoracic kyphosis is theoretically-linked to postural adaptations to large breasts[27], but this is only supported by cross-sectional work that has examined differences in thoracic kyphosis between groups of women categorised by their breast size[23, 53]. It is possible that the non-linearity between breast size and thoracic kyphosis has been concealed by only previously examining breast size as a categorical variable and this may have also led to the over-reporting of differences according to breast size.

The other unexpected finding from our cross-sectional work was the inconsistent trends noted for posture. While significant negative relationships were identified between increasing breast size and posture (Chapter 9), where a more forward head, a more rounded upper back, and more protracted shoulders were confirmed in women with larger breasts, these relationships were of negligible strength. In addition, our UBP study[256a] (Chapter 8) had identified no significant association between posture variables and UBP, which suggested that the postural adaptations to large breasts noted in Chapter 9 and proposed theoretically, may have little relevance to the experience of UBP.

Independent of age, upper back extensor muscle endurance was the only physical characteristic associated with increasing the likelihood *and* severity of UBP (Chapter 8) that was also identified as having a significant negative relationship with breast size (Chapter 9). The relationship between upper back extensor muscle endurance and breast size and between upper back extensor muscle endurance and UBP identified in our cross-sectional work gives some support for considering the theoretical biomechanical relationship that may exist between breast size, upper back extensor muscle endurance and UBP. The function of upper back extensor muscles, whilst not being the focus of early biomechanical theories on breast-related UBP[27], has been considered important in more recent work discussing biomechanical relationships between breast size and posture[23].

In Chapter 9, brief reference was made to speculation that extensor muscles of the upper back could have an important role in offsetting the higher thoracic flexion torques associated with larger breasts[22, 23]. In one theoretical interpretation of our findings, it is possible that in the presence of poor upper back extensor muscle endurance, women with larger breasts may be less able to compensate for greater thoracic flexion torques generated by large breasts. Without leading to permanent changes in posture of thoracic kyphosis (as our data do not support this), this may have implications for the loading and strain of musculoskeletal tissues which could be the basis for them experiencing UBP. This sequence of associations is based on inductive reasoning using the findings of our own cross-sectional work and those of other studies. It is therefore a hypothesis generated from propositional logic that requires more rigorous testing.

In Chapter 10, a cross-sectional study of 117 participants of the postmenopausal subset examined if breast size was associated with prevalent vertebral fracture. The work describes for the first time that postmenopausal women with larger breasts were more likely to have a vertebral fracture, independent of BMD. Although causal relationships cannot be inferred from cross-sectional data, it is important to acknowledge that vertebral fractures could be an important clinical outcome related to larger breast sizes.

Vertebral fractures were identified at a prevalence rate of 15% in our postmenopausal subset which, reflecting two large population studies, is quite typical for women aged over 50 years[316, 317]. In postmenopausal women with osteoporosis, vertebral fractures have significant health, functional and economic implications[1, 90, 94, 318]. However, vertebral fractures have an uncertain relationship with UBP[94, 96]. Although the upper back is rarely specified as the location of 'back pain' in studies of osteoporotic populations, greater severities of back pain have been related to the number of vertebral (T4-L4) fractures[94] and to the age of vertebral (T7-L5) fractures[96]. In Chapter 8 and Chapter 10, there was no significant differences found in pain severity between women with and without vertebral fractures, but women with at least one vertebral fracture were more likely to have UBP (Chapter 10). There could have been methodological reasons that explain why we did not detect differences in UBP severity between our fracture and nil fracture groups, including that the fracture group was relatively small and may not have had a sufficient spread across all possible scores for UBP severity. The finding that vertebral fractures were more likely in women with larger breasts remains clinically important because having a vertebral fracture increases the risk of subsequent fractures[319].

Vertebral fractures have not been previously considered in the mechanism that may explain why women with larger breasts experience greater severities of UBP. Letterman and Schurter[27] suggested that women may be prone to greater spondylitic changes in intervertebral joints as a result of increasing biomechanical loads involved with carrying large heavy breasts. This has been verified to some extent by research using MRI to assess cervical and thoracic intervertebral joints[45]. Vertebral fractures may be another way in which the overloading of skeletal tissues with increasing breast size[27] could manifest. Although speculative, the long-term sequelae of having larger breasts may be a vertebral fracture. Greater thoracic flexion torques[22, 23], poor back extensor muscle function[23, 45, 49] and higher vertebral compression shear loads[57], all previously identified in women with larger breasts, have also been implicated in vertebral fracture risk[320].

Having identified that breast size is associated with prevalent vertebral fractures independent of BMD, our work also suggests that as a potential pathological pathway, this may not be

contingent of bone strength but rather on bone loading[320]. Thoracic kyphosis, although inconsistently related to breast size, may have a place in this pathway as a precursor or consequence of vertebral fractures related to breast size.

In Chapter 11, a cross-sectional study of all 119 participants of the postmenopausal subset that examined musculoskeletal tissue sensitivity in relation to breast size and UBP, breast size was not found to be related to greater sensitivity at any of the selected upper back sites. Using a novel approach of measuring PPTs in upper back musculoskeletal tissues as a marker of potential strain, participants with moderate-severe UBP were found to be more sensitive across most skeletal and muscular tissues than those with nil-mild UBP, regardless of the size of their breasts. This was in contrast to what was hypothesised and raises questions over the putative role of breast size in increasing the strain on upper back musculoskeletal tissues[27].

Although the cross-sectional nature of the approach taken in Chapter 11 does not determine a cause and effect relationship between breast size and tissue sensitivity or between UBP and tissue sensitivity, the study was the first to test the theory that strained and sensitised upper back tissues in women with large breasts would account for their UBP[27]. Despite its limitations, this study provided reasonably strong evidence of a relationship between UBP and localised upper back tissue sensitivity. Breast size however, had no meaningful influence on this relationship. Whether methodological factors explain these results or whether tissue sensitivity measured via PPTs is the best marker of tissue strain are worthy of consideration. From our investigation it looked as though breast size had little do with determining sensitivity in upper back musculoskeletal tissues.

13.7.1 Methodological considerations

By drawing on trends in our cross-sectional data we have begun to understand the potential physical basis for UBP in women with large breasts. Having not prospectively measured physical characteristics as outcomes related to having larger breasts or determinants of UBP, there is a limit to the conclusions that can be drawn and this is acknowledged.

The strengths of the approach taken in Chapters 8, 9 and 11, which add confidence to our findings, included that the methods for measuring posture and PPT were established as reliable (Chapter 3). In addition, the posture variables examined in Chapter 8 and 9 together with the tissues examined in Chapter 11, were selected using sound theoretical grounding[27].

The robust radiographic measure employed in Chapter 10 to examine vertebral fractures associated with breast size was another strength of this work. While the use of DXA to

examine vertebral fractures is noted previously[317], for thoracic vertebrae, the viewing obstruction caused by attaching ribs meant plain radiography was a more accurate and suitable choice of method for detecting thoracic vertebral fractures in our participants. Additionally, the analysis of our X-rays by a single Consultant Radiologist meant that the diagnosis of fractures was based on a single consistent opinion which eliminated potential errors related to discrepancies in interpretation.

Whilst the approach taken in Chapter 11 to examine PPTs was reliable, it was also exploratory and there are some limitations worth noting. In order to test the theory of Letterman and Schurter[27] more specifically, it could have been informative to assess sensitivity alongside other potential markers of tissue strain such as muscle length and strength tests. This may have provided a more complete evaluation of the theory which refers to many possible adaptations in musculoskeletal tissues including them becoming tensioned, shortened, weakened and fatigued. Analysing tissue sensitivity in relation to participants head, upper back and shoulder posture could also have provided further insight into the theory because postural changes are thought to underlie the chronic stress of musculoskeletal tissues yet as we have found in Chapter 8, posture appears to have an uncertain relationship with UBP. Finally, in contrast to other studies that have used digital algometry to characterise musculoskeletal pain conditions[321-323], we did not employ a reference/control test site. This was a significant limitation because by not assessing the sensitivity of an unrelated remote test site, we cannot be certain that the sample had equivalent pain perception at baseline. This means that generalised hyperalgesia cannot be entirely excluded as a confounding factor despite our argument that volunteers with chronic pain were likely to have been omitted with our exclusion criteria in place.

13.7.2 Clinical and research implications of thesis research question 5

The work of this thesis has developed some of the much-needed theoretical rationale to support the physical basis for UBP in women with larger breasts. In an extension of existing theories, upper back extensor muscle endurance that is lower in women with larger breasts (Chapter 9) and that may increase their likelihood for UBP (Chapter 8), is proposed as a characteristic that may be central to explaining why some women with large breasts experience UBP. Future research may examine upper back extensor muscle endurance and its protective association with UBP in women with large breasts to secure further support that this is as a modifiable characteristic that can offset greater thoracic flexion torques associated with larger breasts[22, 23] and in doing so can reduce the possible strain on musculoskeletal tissues[27]. Vertebral fractures that are more likely in women with larger breasts irrespective of their BMD, also need verification from prospective investigations to

confirm that they are a possible clinical outcome of this pathological pathway. It may then be possible to broach the question of what can or should be done about this.

Our cross-sectional findings provided no support for the theory and anecdotal evidence that thoracic kyphosis and posture are closely related to UBP in women with large breasts. This was an unexpected outcome. We did note in response to thesis research question 4 however, that our sample had above average upper back extensor muscle endurance when compared to age-referenced norms. Previously, the severity of thoracic kyphosis has been reported to be influenced by the strength of back extensor muscles[110, 111, 324] and it is possible that in our sample, the relationship between breast size and thoracic kyphosis was not detected owing to their superior upper back extensor muscle endurance (refer to section 13.6). On the basis of supporting evidence, it is possible that differences in upper back extensor strength or endurance may also contribute to explaining why relationships between breast size and thoracic kyphosis have not been consistently reported in the past. Future research could examine upper back extensor muscle endurance as a mediating factor in the relationship between breast size and thoracic kyphosis.

Our use of digital algometry to measure PPT also provided no evidence to support existing theories that larger breasts lead to greater strain on musculoskeletal tissues. The exploratory nature of our work to investigate tissue strain using PPTs didn't account for the likelihood that a number of factors other than tissue strain could influence the perception of pressure pain. Further work is needed to confirm that muscles under strain can be adequately differentiated from those that are not under strain using PPTs while controlling for confounding factors. Pressure pain thresholds provide a useful objective indicator of tissue sensitivity. However, the high variability of PPTs between participants and measurement sites which was clear from our study, and which is consistent with previous research[325, 326], creates a real challenge for singling out breast size as a stand-alone factor related to tissue sensitivity.

The exploratory work on vertebral fractures and tissue sensitivity serves to raise the awareness of clinicians to the possibility that in their assessment of postmenopausal women with larger breasts and upper back pain, they may expect some findings to be common. These include a higher likelihood of vertebral fractures in the mid to lower thoracic spine in women with larger breasts, and greater tenderness of upper back musculoskeletal tissues, particularly middle trapezius, in women with moderate-severe UBP. Whether these relate as causes or consequences of UBP or whether they can be modified with treatment are not confirmed from this doctoral research, but clinicians may consider them as possibilities.

Proposing upper back extensor endurance as a key physical characteristic in breast-related UBP creates exciting avenues for future research where this may be assessed and targeted in controlled therapeutic trials to evaluate its effect on UBP in women with large breasts. Confirming its effectiveness could encourage the prescription of upper back extensor muscle training in clinical settings where the goal may not only be to relieve UBP but also to offset the need of reduction mammoplasty.

13.7.3 Summary

In answer to the fifth research question of the thesis, upper back extensor muscle endurance and vertebral fractures are physical characteristics related to breast size that, with further prospective validation, may support a physical basis for UBP in women with large breasts.

13.8 Thesis research question 6. Which characteristics, relevant to upper back pain, that change following reduction mammoplasty, progress understanding of the relationship between breast size and upper back pain?

The purpose of the sixth and final objective of this thesis was to cross-examine the cross-sectional findings of Chapter 6 to 11 with the prospective work of Chapter 12, a longitudinal study of 11 women that evaluated the change in self-report (aspects of the health and psychological wellbeing) and physical characteristics in relation to reduction mammoplasty. Characteristics associated with UBP in the cross-sectional work of Chapters 7 and 8 provided a focus for examining breast satisfaction, SF-36 PCS scores, and upper back extensor muscle endurance in the surgical sample before and after reduction mammoplasty. As noted in response to thesis research questions 2 and 5, some confirmation that these characteristics were negatively related to breast size has been provided in the cross-sectional findings of Chapters 6 and 9. The prospective work of Chapter 12, however, was to provide further validation that these characteristics were not only negatively related to larger breast sizes and UBP but also that they are relevant markers of UBP improvement following reduction mammoplasty. Identifying the rate and clinical meaningfulness of change in these specific characteristics relative to UBP severity following reduction mammoplasty was to yield support for a theoretical relationship between breast size and UBP that may involve these factors as potential mediators. In addition, having produced novel findings from our cross-sectional work that identified a relationship between breast size and vertebral fractures, looking at the prevalence of vertebral fractures was also of interest in our examination of the surgical sample. The unexpected finding from our cross-sectional work that we also looked to confirm was that breast size was not associated with differences in upper back

musculoskeletal tissue sensitivity. Our cross-sectional work had confirmed that greater localised tissue sensitivity aligned with more severe UBP but not with larger breast sizes, so it was of interest to cross-examine the tissues showing significant changes in sensitivity with the reduction in breast size and improvements in UBP that we anticipated in the surgical sample.

The mean age of the surgical sample (57.3 years) was comparable to that of the community-based sample (58.2 years) and the postmenopausal subset (61.4 years) providing reasonable grounds to cross-examine characteristics relevant to UBP between these samples. For ease of reference the results of Chapter 7, 8 and 12 are summarised in Table 13.1.

Table 13.1 Cross-examination of characteristics relevant to upper back pain between cross-sectional samples and surgical sample (mean (SD))

	Community-based sample			Postmenopausal subset			Surgical sample			
	Whole sample	UBP	Nil UBP	Whole sample	UBP	Nil UBP	Pre-surgery	3-months post-surgery	6-months post-surgery	12-months post-surgery
n	269	165	104	119	61	58	11	11	11	11
Mean age (years)	58.2 (9.1)	56.7 (9.0)	60.6 (8.8)	61.4 (7.0)	59.1 (6.6)	63.8 (6.6)	57.3 (9.4)	-	-	-
Breast satisfaction (0-100)	47.6 (17.7)	43.0 (16.7)	54.8 (16.8)	-	-	-	22.1 (18.5)	67.4 (23.0)	69.4 (23.8)	67.4 (23.3)
SF-36 PCS scores (0-100)	47.4 (8.5)	45.2 (8.5)	50.9 (7.3)	-	-	-	43.2 (5.3)	50.2 (7.8)	50.4 (10.4)	51.2 (10.7)
Upper back extensor muscle endurance (0-300s)	-	-	-	99.1 (72.6)	81.8 (53.2)	117.3 (85.3)	136.7 (81.4)	164.3 (106.6)	177.4 (108.7)	167.5 (102.4)

Abbreviations: UBP – Upper back pain; SF-36 PCS – The Medical Outcomes Study Short Form 36 Health Survey physical component summary.

Upper back pain

To be able to establish the characteristics relevant to UBP that change following reduction mammoplasty, the nature, magnitude and rate of change in UBP NRS scores were first important to analyse. Preoperatively, participants in the surgical sample had mild severities of UBP. These were comparable to UBP severities reported preoperatively in some previous reduction mammoplasty samples[42, 69] but were lower than those reported more commonly by women seeking this surgery[25, 26, 40, 41, 70]. The surgical sample reported similar levels of UBP severity (mean (SD) NRS 4.5 (2.2)) to those reported by participants with UBP in the postmenopausal subset (mean (SD) NRS 4.6 (2.1)).

Despite preoperative UBP severity being mild, the 80% improvement in UBP severity scores recorded for participants in the surgical sample following reduction mammoplasty (Chapter 12) was comparable in magnitude to improvements previously recorded[25, 40, 42, 70]. The rate at which UBP improved in the surgical sample was difficult to compare to existing accounts as the rate of improvement has typically had less focus than the magnitude of change in previous research. Follow-up times varied considerably in existing surgical studies with UBP improvements previously recorded as early as 3-months postoperatively in prospective studies[42] but also as distant as 6 years postoperatively in retrospective studies[26]. The greatest improvement in UBP severity recorded for the surgical sample occurred at 6-months post-surgery, where pain was almost absent for most participants. Improvements in UBP persisted to 12-months postoperatively where severity scores were still significantly improved on preoperative levels.

Breast satisfaction

Preoperatively, participants in the surgical sample had breast satisfaction scores that were well-below referenced norms of (mean (SD)) 57 (16)[163], but that were comparable to younger women (aged <60 years) in other surgical studies preoperatively[76, 196]. Breast satisfaction scores in the surgical sample were also substantially lower than those in the community-based sample overall and in those participants of the community-based sample with UBP (Table 13.1). This suggested that age was unlikely to be the basis of this difference. Given that 'back pain' was cited as the primary reason for seeking reduction mammoplasty, participants in the surgical sample may have had greater focus on their breast size as a particular cause of their UBP. It is, therefore, perhaps not unexpected that the surgical sample recorded greater levels of breast dissatisfaction compared to the community-based sample.

The 214% increase in breast satisfaction following reduction mammoplasty, placed the improvements seen in our surgical sample slightly lower compared to those cited previously where improvements have exceeded 300%[76, 196]. Prior studies have reported these improvements earlier in the postoperative period, within one month[73] and within 6-weeks[76] of surgery. In contrast, the greatest breast satisfaction improvement in our surgical sample did not occur until 6-months post-surgery. The improvements in breast satisfaction did, however, still align closely with UBP improvement.

Postoperatively, breast satisfaction scores in the surgical sample exceeded the scores of women without UBP in the community-based sample (Table 13.1) and surpassed referenced norms[163]. The normalisation of breast satisfaction probably understates the effect of reduction mammoplasty on this characteristic and the simultaneous change in breast satisfaction alongside UBP postoperatively supports a relationship between these variables. Although the surgical sample was small in size, which does limit confidence in drawing conclusions, the scores for breast satisfaction improved in a similar trend to UBP severity, providing further evidence that supports the theory that how a woman feels about her breasts is potentially an important element of her UBP experience.

Physical component summary scores

Preoperatively, SF-36 PCS scores for the surgical sample were comparable to those noted in younger women preoperatively where mean scores of 40-44 have been reported[70, 74, 172] but were meaningfully below referenced norms for Australian women of similar age (mean (SD) 49.5 (9.3))[176]. Compared to participants with UBP in the community-based sample, SF-36 PCS scores amongst the surgical sample preoperatively were also marginally lower (Table 13.1).

Physical component summary scores improved steadily with time for participates in our surgical sample and by amounts similar to those recorded previously following reduction mammoplasty[70, 74, 172]. The normalisation of SF-36 PCS scores was noted for our surgical sample participants with the greatest mean percentage increase (18%) at 12-months post-surgery. This took their mean scores beyond those recorded for participants without UBP in the community-based sample (Table 13.1). Improvements in SF-36 PCS scores were also not associated with age, BMI or breast resection weight which is consistent with previous accounts[70, 72].

The scale and rate of improvement in SF-36 PCS scores were different to that that of UBP severity. The improvement in UBP following reduction mammoplasty is likely to have had a positive effect on SF-36 PCS scores with pain being captured as part of this score[133]. The

slower rate of improvement noted in SF-36 PCS scores compared to UBP severity, may therefore simply reflect the slower return of physical function and health over time. The findings of Chapter 12 showed physical activity levels trending upwards over time and although these changes were not significant, the changes may be just one way in which participants adapted to their new breast size. The health benefits of increasing physical activity alone could have had a progressive and accumulating benefit on SF-36 PCS scores[275].

Upper back extensor muscle endurance

It was an unexpected finding that upper back extensor muscle endurance levels in the surgical sample preoperatively would be reasonably high. The mean levels of endurance preoperatively (Table 13.1) placed women in the surgical sample between the 50th and 75th percentile for age-referenced norms for upper back extensor muscle endurance[115]. These were also greater than those levels reported previously for healthy, younger (mean age 47 years) women (mean (SD) 128.4 (53.0)s, n=53)[230]. The surgical sample also had better levels of upper back extensor muscle endurance than participants with UBP (Table 13.1), but also those without UBP in the postmenopausal subset (Table 13.1). In light of these comparisons, we have not been able to confirm that levels of upper back extensor muscle endurance were a defining feature of the surgical sample relevant to their experience of UBP preoperatively. The findings from our small surgical sample are also not consistent with what has been observed in previous work involving women with hypertrophic breasts[45] or women seeking reduction mammoplasty[49], where decreased muscle strength has been reported.

Upper back extensor muscle endurance, whilst not showing a statistically significant change following reduction mammoplasty, improved at a similar rate to UBP. However, the improvements in upper back extensor muscle endurance were not large (30%) and this may have been due to a ceiling effect owing to the high pre-surgery endurance levels in this sample. All things considered, it appears that improvements in upper back extensor muscle endurance may be less potent in explaining UBP improvements with reduction mammoplasty, despite this being identified as a factor associated with UBP in our cross-sectional work[256a] (Chapter 8).

Of note, according to the work of Chapter 8, a change in upper back extensor endurance of 72.6s (one-standard deviation change) would confer a reduction in UBP severity of 0.91 points on a 0-10-point NRS scale. Since a change of 2-points on the 0-10 NRS scale is considered the minimum that is clinically important[155], a change in upper back extensor endurance greater than 145.2s was needed postoperatively to reduce UBP severity by a

clinically meaningful amount. As the greatest mean (SD) change in upper back muscle endurance pre to postoperatively was 41(73)s, this fell well short of this threshold.

Vertebral fractures

The cross-sectional work of this project highlighted with some uncertainty that vertebral fractures may be relevant to the experience of UBP in women with larger breasts. A cross-examination of findings between samples showed the surgical sample had a greater prevalence of vertebral fractures (27%, n=11) than was recorded amongst the postmenopausal subset (15%, n=117) (Chapter 10) and amongst participants with UBP in the postmenopausal subset (21%, n=61), all of whom had identical BMD. This prevalence rate, whilst drawn from a very small surgical sample size, is noteworthy because it is not only inflated in comparison to our own cross-sectional samples, but it is also more than double the prevalence rate reported from a large population study that included women under 60 years (3.4%, n=412) and women aged 60-69 years (11.1%, n=721)[317]. These findings provide further evidence of a possible relationship between breast size and vertebral fractures that may warrant further investigation.

The prevalence of vertebral fractures is not changed by reduction mammoplasty, making it difficult to explain the relevance of fractures to UBP when UBP improves postoperatively. However, postoperative changes in biomechanical loading of sensitive bone tissue may explain this relief[27].

Upper back musculoskeletal tissue sensitivity

The surgical sample preoperatively showed marginally greater tissue sensitivity (lower PPTs) compared to the postmenopausal subset across all anatomical sites (Figure 13.2). In addition, PPTs at some sites were marginally lower in the surgical sample preoperatively when compared to referenced norms[248, 322, 327, 328]. However, it is difficult to know if these are meaningful when differences were small and normative samples were, by comparison, healthy, often younger and also did not have UBP.
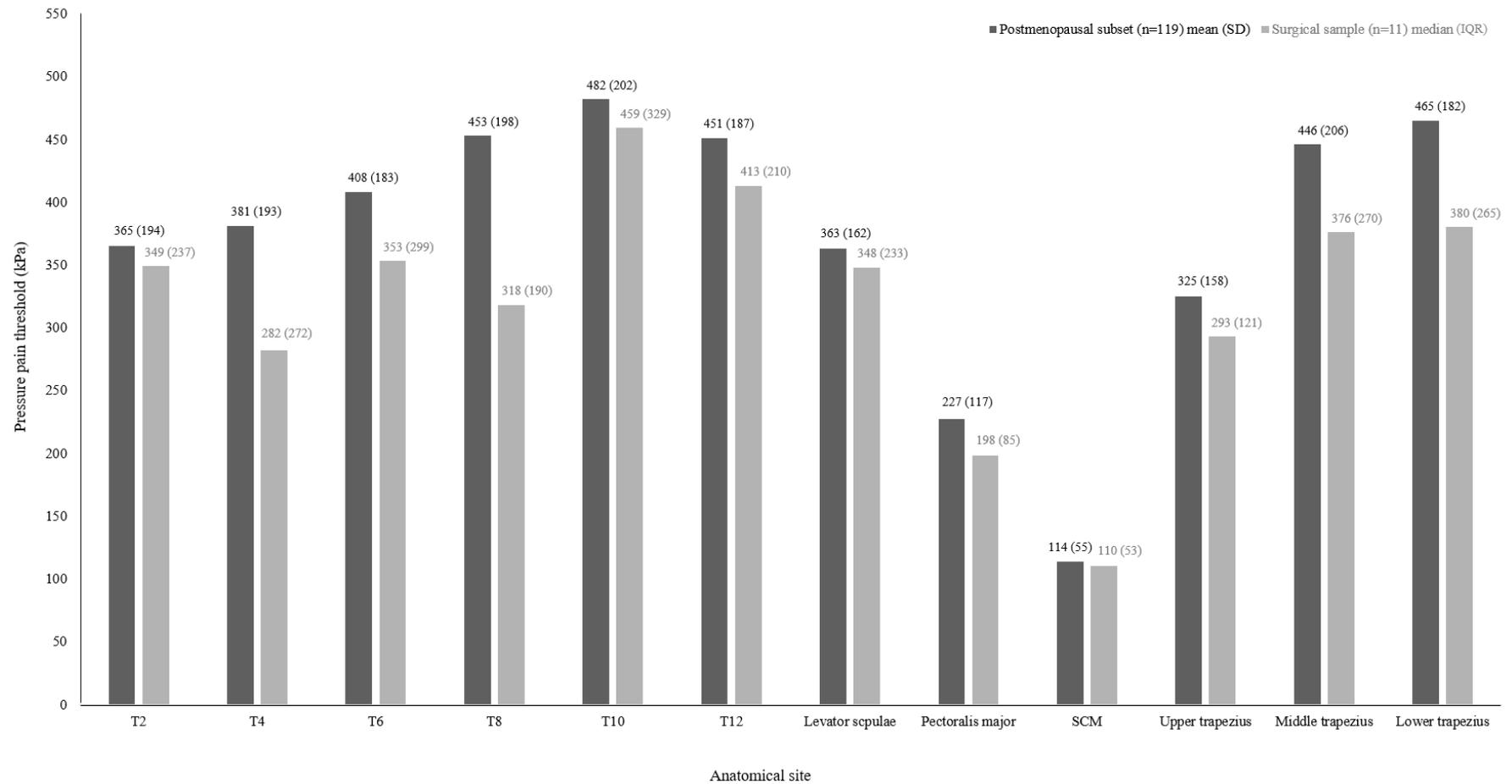
Figure 13.2 Comparing pressure pain thresholds across twelve anatomical sites between the postmenopausal subset (n=119) and surgical sample (n=11)
Abbreviations: kPa – Kilopascals; SD –Standard deviation; IQR – Interquartile range; SCM – sternocleidomastoid

Assessing the change in musculoskeletal tissue sensitivity occurring following reduction mammoplasty was a novel approach to investigate whether a reduction in breast size improves how musculoskeletal tissues in the upper back feel and whether this was relevant to UBP. Since there was no clear relationship between breast size and upper back musculoskeletal tissue sensitivity identified in the work of chapter 11, it was unsurprising that we measured little change in PPTs in the postoperative period. Levator scapulae was the only site that significantly improved in sensitivity in the surgical sample following reduction mammoplasty. This provides further support that sensitivity of upper back musculoskeletal tissues are probably not strongly related to breast size or changes thereof.

13.8.1 Methodological considerations

Although the size of the surgical sample undoubtedly limits the inferences that can be made from the work of Chapter 12 and the generalisation of its findings, our within-subject design that had many repeated measures offered good power to explore the meaning of the results. In addition, there were careful methodical steps taken to screen the data for normality where the postmenopausal subset dataset were used for reference. Confidence was gained in interpreting the significance of pre-to-post-surgery changes using parametric test results knowing this screening process had been completed but also by comparing parametric and non-parametric test results. This demonstrated attention to the likelihood of false-positive results and, by presenting the margins of error for each characteristic that was tested at each time point, the reader is able to gauge if there was some evidence of effect, even though the change may have missed statistical significance.

With such strong theoretical grounding for a physical basis for UBP in women with large breasts, it is important to consider why our work identified so few physical characteristics changing in relation to UBP following reduction mammoplasty. The small size of the surgical sample was a possible reason that significant changes in upper back extensor muscle endurance were not registered when we had reasonable basis for expecting that it would. The variability around the mean preoperative upper back extensor muscle endurance times for participants in the surgical sample was greater than that for the larger sample of postmenopausal women with UBP (Table 13.1), which was one element of the data that suggested this. It is possible that we did not capture a truly representative picture of upper back extensor muscle endurance times from our 11 participants preoperatively. It is also possible that our surgical sample included women who were overall fitter than average. Preoperative physical activity levels indicated that they were moderately active which is somewhat uncharacteristic for women seeking reduction mammoplasty who commonly complain of physical activity limitations because of their breast size[26]. With these things

considered, it is arguably still worth contemplating upper back extensor muscle endurance as a relevant characteristic to UBP in women with larger breasts and until further work has been completed with larger surgical samples, its relevance to the clinical picture of UBP, remains possible.

The limitations of the work presented in Chapter 12 include that we did not longitudinally assess the characteristics of interest in a control group. A control group would have provided a benchmark for assessing the changes in the surgical sample over time. It may have been particularly informative to match participants in the surgical sample with controls of similar age, breast size and with similar UBP severity to be more certain of how the changes in breast size with reduction mammoplasty were associated with measured characteristics that also changed.

We also did not consider the potential role of co-morbidities in affecting pre-to-post-surgery characteristic changes. Although age and BMI were some of the things we did evaluate as potential influences, it is acknowledged that 'number of comorbidities' has been previously cited to affect outcomes following reduction mammoplasty[70].

Another element that we did not evaluate or control for was the participant's expectations from surgery. Considering what a patient expects from surgery could be potentially important. Having expectations that surgery was going to relieve UBP could have contributed to changes in UBP observed in the sample.

Finally, it is important to acknowledge that although UBP was the focus of this study, participants articulated a range of reasons, in addition to UBP, for undergoing surgery (refer to Chapter 12, Table 12.2). The characteristics that change following surgery may have also been influenced by improvement in these co-existing preoperative symptoms.

13.8.2 Clinical and research implications of thesis research question 6

The improvement in UBP recorded in the work of Chapter 12 first adds to the body of evidence demonstrating the long-term benefit of reduction mammoplasty on UBP[25, 26, 69]. This provides clinicians with confidence in discussing the favourable outcomes that are possible from this surgery.

The longitudinal study of such an extensive array of characteristics had also not been previously attempted and the work represents the first of its kind to collectively consider physical and self-report characteristics in relation to UBP with reduction mammoplasty. The findings have produced unexpected results, the most notable of which was that improvements following reduction mammoplasty are primarily seen in self-report variables

and not in physical characteristic changes. By considering more than just a single or small groups of characteristics that change with UBP in relation to reduction mammoplasty, the novel approach we took has highlighted the biopsychosocial nature of UBP in women with larger breasts. This supports the findings of our cross-sectional work presented in prior chapters.

A common theme in existing reduction mammoplasty literature is to examine the postoperative improvement in symptoms relative to the amount of breast tissue resected to provide some indication of whether minimum resection amounts are needed to confer the benefits of reduction mammoplasty. For UBP, our results were in agreement with past studies by showing that improvements in UBP severity were unrelated to the amount of breast tissue resected[25, 26, 41, 42]. This adds to the general consensus that improvements following reduction mammoplasty occur 'at any size' which lends further weight to the proposition that a criterion-based approach to deciding funding for the procedure should not be on resection weight alone[41, 42, 283, 284].

Another implication of the findings from our small but comprehensive look at the characteristics of women undergoing reduction mammoplasty was the lack of physical characteristics that definably improve alongside UBP following surgery and overall. This was an unexpected outcome. Predicting the success of reduction mammoplasty is of significant clinical interest and attempts have been made in the past to develop predictive models of success using objectively-measured physical characteristics of patients as predictors[26]. Understanding the likelihood of symptoms such as UBP improving with reduction mammoplasty could help to give clinicians grounding for recommending the surgery and could help to inform health insurance companies on the appropriate allocation of funding for the procedure. While it was not possible to generate predictive models from the data collected from our small sample, for future research, our findings suggest that less focus should be given to physical characteristics as potential predictors of UBP improvement following reduction mammoplasty. Instead, predictive models may be more successfully developed using information of how patients feel about their breasts.

Significant improvements in breast satisfaction and SF-36 PCS scores that co-occur with improvements in UBP following reduction mammoplasty provide further support for a theoretical relationship between breast size and UBP that is contributed to by these self-report aspects of health and psychological wellbeing. The physical basis for UBP in women with large breasts remains unclear after cross-examining the physical characteristics related to UBP with those that change following reduction mammoplasty. Further consideration needs to be given to understanding UBP related to breast size. The cross-sectional and

prospective work of this project indicates this is likely to have a complex aetiology which may have more to do with how a woman perceives her breasts and how she believes they affect her UBP and physical health, rather than on the actual size of her breasts or on her physique. Steering the traditional biomechanical theories towards a more biopsychosocial approach to explaining UBP in women with large breasts is a consideration for future research.

In addition to UBP, the work of Chapter 12 also captured information of neck and shoulder pain which improved in similar ways to UBP following reduction mammoplasty. Our findings suggest that breast satisfaction and SF-36 PCS scores may have relevance to explaining relationships between breast size and neck and shoulder pain conditions. The relationships between breast size and these conditions have received less research attention than UBP in the past but could be another avenue for future work that is encouraged by our findings which show these also improve by clinically meaningful amounts following reduction mammoplasty.

For clinicians, the finding that UBP in women with large breasts could have a biopsychosocial orientation is useful. When working with women with large breasts presenting with UBP, clinicians may consider addressing breast perceptions and managing the perceived impact on physical function. These could be effective ways to help manage the UBP. Targeting the improvement of upper back extensor muscle endurance is also something that might be considered. While further work needs to confirm if this is characteristic relevant to UBP in women with large breasts seeking reduction mammoplasty there is reasonable indication from our cross-sectional work to suggest that having better upper back extensor muscle endurance could protect against UBP.

13.8.3 Summary

In answer to the sixth research question of this thesis, breast satisfaction and SF-36 PCS scores are two self-report characteristics relevant to UBP that improve with reduction mammoplasty. This provides some support that these self-report characteristics, are aspects of health and psychological wellbeing that are important to the experience of UBP in women with larger breasts. Upper back extensor muscle endurance, being a characteristic relevant to UBP, showed only small improvement post-surgery. Vertebral fractures, noted with greater prevalence in women seeking reduction mammoplasty, are a physical characteristic that are further supported as being potentially relevant to the clinical picture of UBP in women with large breasts.

13.9 Thesis conclusion

The broad and ambitious aim of this doctoral research project was to explore the relationship between breast size and UBP. The approach taken to address this aim has considered the theories underpinning the likelihood of a relationship between breast size and UBP and the multifactorial nature of UBP. In doing so, an extensive scope of research has been undertaken where the challenge has been to build a body of empirical evidence that helps to advance understanding of the relationship between breast size and UBP beyond its theoretical foundation. In addition to the different and sizeable research fields that have been referred to throughout this thesis, the difficulty of measuring breast size precisely and the multifactorial nature of UBP have made the relationship between breast size and UBP challenging to research.

The findings from this doctoral research indicate that the relationship between breast size and UBP is complex. In mature-aged women at least, the relationship is not strong or well-defined. Not all women with larger breasts experience UBP and this has made it difficult to identify the characteristics that make it more severe in those that do and to be sure of the reasons for this. The difficulty in precisely measuring breast size is also a factor that adds uncertainty to the relationship. Whilst not the perfect measure, the BSS method provided a best estimate of breast size given the time and resources available for the project. It is important to acknowledge that the relationships identified between breast size and UBP could have been limited by the accuracy and precision of the BSS method.

In this thesis, breast size has been referred to and explored in relation to UBP as both an explanatory and predictive factor[329]. Statistical models presented in Chapters 6-8 were developed with the dual purpose of both explaining the presence and severity of UBP as well as estimating how much more likely UBP was to be present with increments of breast size. Similarly, the statistical models presented in Chapter 9-11 were developed with the purpose of exploring the plausible explanatory power of breast size in relation to physical characteristics that are putatively linked to UBP via biomechanical theories. The selection of breast size alongside other potential associated factors in most of these models was theoretically-based which was fitting for a thesis which had an exploratory approach. Breast size as an 'associated risk factor' should be interpreted to mean that it contributed, relative to other factors, to explaining UBP, and by increasing the odds, this looked to be in a negative way although causation was theoretically-based. It is acknowledged that with the cross-sectional nature of most of the data collected in this thesis, there is no certainty that breast size can be formally described as a 'risk factor' for UBP. In addition, it is appreciated that assumptions have been made when developing the statistical models and these include the

limited control of confounding and mediation effects between breast size and other factors that may have been possible.

There are aspects of health and psychological wellbeing, including how satisfied a woman is with her breasts and how she perceives her physical health, that are important, perhaps more so than breast size itself, in explaining UBP. There are few definable physical characteristics that can be confidently described as strong associated risk factors for UBP in mature-aged women with large breasts. The roles of upper back extensor muscle endurance and vertebral fractures in the clinical picture of UBP in women with large breasts are suggested but not proven by the work in this thesis.

This thesis makes a significant and original contribution to several fields of research in addition to advancing theoretical knowledge on the relationship between breast size and UBP. The work of Chapter 5 contributes to the field of medical and diagnostic imaging by presenting original work that identifies radiographic methods to be more accurate than Flexicurve in measuring thoracic kyphosis in postmenopausal women. The work of Chapter 6 contributes to the field of women's health by presenting the first evidence to identify that aspects of health and psychological wellbeing are negatively related to larger breast sizes in mature-aged women. The work of Chapter 8 contributes to the field of UBP research and represents the first comprehensive exploration of physical characteristics associated with UBP in postmenopausal women. Chapter 10 contributes to the field of bone and mineral research by identifying breast size as a novel associated risk factor of vertebral fractures. Chapter 11 contributes to the field of breast research where an objective method (PPT) was used to test the theoretical basis for UBP in women with large breasts. Finally, Chapter 12 contributes to the field of plastic and reconstructive surgery where, using an original approach of examining a large collection of characteristics, the nature, rate, and significance of those that improve alongside UBP have been prospectively described.

For there to be more certainty in understanding the relationship between breast size and UBP it is imperative that prospective work be undertaken on this topic. This is a huge challenge when breast size and UBP experiences vary over time and are so difficult to assess accurately and objectively. For a relationship that seems so obvious and logical, there is plenty more to do in proving and explaining it.

References

1. Huang C, Ross PD, Wasnich RD. Vertebral fractures and other predictors of back pain among older women. J Bone Miner Res. 1996; 11: 1026-1032. DOI: 10.1002/jbmr.5650110721.

2. Briggs A, Bragge P, Smith AJ, Govil D, Straker L. Prevalence and associated factors for thoracic spine pain in the adult working population: a literature review. J Occup Health. 2009; 51: 177-192. DOI: 10.1539/joh.K8007.

3. Fouquet N, Bodin J, Descatha A, Petit A, Ramond-Roquin A, Ha C, et al. Thoracic spinal pain prevalence in the musculoskeletal disorders surveillance network of the French Pays de la Loire region. Occupd Environ Med. 2014; 71: A24-A24. DOI: 10.1136/oemed-2014-102362.74.

4. Parsons S, Breen A, Foster NE, Letley L, Pincus T, Vogel S, et al. Prevalence and comparative troublesomeness by age of musculoskeletal pain in different body locations. Fam Pract. 2007; 24: 308-316. DOI: 10.1093/fampra/cmm027.

5. Roquelaure Y, Bodin J, Ha C, Le Marec F, Fouquet N, Ramond-Roquin A, et al. Incidence and risk factors for thoracic spine pain in the working population: the french pays de la loire study. Arthritis Care Res. 2014; 66: 1695-1702. DOI: 10.1002/acr.22323.

6. Australian Bureau of Statistics. Population projections, Australia, 2012 (base) to 2021. Canberra: Austraian Bureau of Statistics (ABS), 2013 [cited 2014 Aug 31] . Available from: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3222.0main+features52012%20(base)%20to%202101.

7. Deaprtment of Health. National women's health strategy 2020-2030. Canberra, ACT: Australian Department of Health, 2018 [cited 2019 Jan 03]. Available from: https://www1.health.gov.au/internet/main/publishing.nsf/Content/AF504671BA9786E8CA2583D6000AFAE7/$File/National%20Womens%20Health%20Strategy%202020-2030.pdf.

8. van der Windt DA, Dunn KM, Spies-Dorgelo MN, Mallen C, Blakenstein A, Starlman W. Impact of physical symptoms on perceived health in the community. J Psychosom Res. 2008; 64: 265-274. DOI: 10.1016/j.jpsychores.2007.10.003.

9. Delloitte Access Economics. The cost of pain in Australia. 2019. ACT, Australia. Pain Australia 2019 [cited 2019 July 01]. Available at: https://www.painaustralia.org.au/static/uploads/files/the-cost-of-pain-in-australia-final-report-12mar-wfxbrfyboams.pdf.

10. Drzal-Grabiec J, Snela S, Rykala J, Podgorska J, Banas A. Changes in the body posture of women occurring with age. BMC Geriatr. 2013; 13: 108. DOI: 10.1186/1471-2318-13-108.

11. Milne JS, Williamson J. A longitudinal study of kyphosis in older people. Age Ageing. 1983; 12: 225-233.

12. Puche RC, Morosano M, Masoni A, Jimeno N, Bertouluzzo S, Podadera J, et al. The natural history of kyphosis in postmenopausal women. Bone. 1995; 17: 239-246. DOI: 10.1016/8756-3282(95)00212-v.

13. Ryan PJ, Blake G, Herd R, Fogelman I. A clinical profile of back pain and disability in patients with spinal osteoporosis. Bone. 1994; 15: 27-30. DOI: 10.1016/8756-3282(94)90887-7.

14. Kado DM, Huang MH, Karlamangla AS, Cawthon P, Katzman W, Hillier T, et al. Factors associated with kyphosis progression in older women: 15 years experience in the atudy of osteoporotic fractures. J Bone Miner Res. 2013; 28: 179-187. DOI: 10.1002/jbmr.1728.

15. Waterloo S, Nguyen T, Ahmed LA, Center J, Morseth B, Nguyen N, et al. Important risk factors and attributable risk of vertebral fractures in the population-based Tromso study. BMC Musculoskelet Disord. 2012; 13: 163. DOI: 10.1186/1471-2474-13-163.

16. Ensrud KE, Black DM, Harris F, Ettinger B, Cummings S. Correlates of kyphosis in older women. The Fracture Intervention Trial Research Group. J Am Geriatr Soc. 1997; 45: 682-687.

17. Ettinger B, Black DM, Palermo L, Nevitt M, Melnikoff S, Cummings S. Kyphosis in older women and its relation to back pain, disability and osteopenia: The study of osteoporotic fractures. Osteoporos Int. 1994; 4: 55-60.

18. Roux C, Fechtenbaum J, Kolta S, Said-Nahal R, Brior K, Benhamou, C. Prospective assessment of thoracic kyphosis in postmenopausal women with osteoporosis. J Bone Miner Res. 2010; 25: 362-368. DOI: 10.1359/jbmr.090727.

19. Hinman MR. Comparison of thoracic kyphosis and postural stiffness in younger and older women. Spine J. 2004; 4: 413-417. DOI: 10.1016/j.spinee.2004.01.002.

20. Granito RN, Aveiro MC, Rennó ACM, Oishi J, Driusso P. Degree of thoracic kyphosis and peak torque of trunk flexors and extensors among healthy women. Rev Bras de Ortop. 2014; 49: 286-291. DOI: http://dx.doi.org/10.1016/j.rboe.2014.04.002.

21. Lin I, Wiles L, Waller R, Goucke R, Nagree Y, Gibberd M, et al. What does best practice care for musculoskeletal pain look like? Eleven consistent recommendations from high-quality clinical practice guidelines: systematic review. Br J Sports Med. 2019. DOI: 10.1136/bjsports-2018-099878.

22. Coltman CE, Steele JR, McGhee DE. Effect of breast size on upper torso musculoskeletal structure and function: A cross-sectional study. Plast Reconstr Surg. 2019; 143: 686-695. DOI: 10.1097/prs.0000000000005319.

23. McGhee D, Coltman KA, Riddiford-Harland DL, Steele J. Upper torso pain and musculoskeletal structure and function in women with and without large breasts: A cross sectional study. Clin Biomech. 2018; 51: 99-104. DOI: 10.1016/j.clinbiomech.2017.12.009.

24. Spencer L, Briffa K. Breast size, thoracic kyphosis & thoracic spine pain - association & relevance of bra fitting in post-menopausal women: a correlational study. Chiropr Man Ther. 2013; 21: 1-8.

25. Atterhem H, Holmner S, Janson PE. Reduction mammaplasty: symptoms, complications, and late results. A retrospective study on 242 patients. Scand J Plast Reconstr Surg Hand Surg. 1998; 32: 281-286.

26. Miller AP, Zacher JB, Berggren RB, Falcone R, Monk J. Breast reduction for symptomatic macromastia: can objective predictors for operative success be identified? Plast Reconstr Surg. 1995; 95: 77-83.

27. Letterman G, Schurter M. The effects of mammary hypertrophy on the skeletal system. Ann Plast Surg. 1980; 5: 425-431.

28. Risius D, Thelwell R, Wagstaff CRD, Scurr J. The influence of ageing on bra preferences and self-perception of breasts among mature women. Eur J Ageing. 2014; 11: 233-240. DOI: 10.1007/s10433-014-0310-3.

29. den Tonkelaar I, Peeters PHM, van Noord PAH. Increase in breast size after menopause: prevalence and determinants. Maturitas. 2004; 48: 51-57. DOI: 10.1016/j.maturitas.2003.10.002.

30. Checka CM, Chun JE, Schnabel FR, Lee J, Toth H. The relationship of mammographic density and age: implications for breast cancer screening. Am J Roentgenol. 2012; 198: W292-295. DOI: 10.2214/ajr.10.6049.

31. Coltman CE, Steele JR, McGhee DE. Effect of aging on breast skin thickness and elasticity: implications for breast support. Skin Res Technol. 2017; 23: 303-311. DOI: 10.1111/srt.12335.

32. Burton A, Maskarinec G, Perez-Gomez B, Vachon C, Miao H, Lajous M, et al. Mammographic density and ageing: A collaborative pooled analysis of cross-sectional data from 22 countries worldwide. PLoS Med. 2017; 14: e1002335. DOI: 10.1371/journal.pmed.1002335.

33. Hammann-Kloss JS, Bick U, Fallenberg E, Engelken F. Volumetric quantification of the effect of aging and hormone replacement therapy on breast composition from digital mammograms. Eur J Radiol. 2014; 83: 1092-1097. DOI: 10.1016/j.ejrad.2014.03.028.

34. Frederick DA, Peplau A, Lever J. The barbie mystique: satisfaction with breast size and shape across the lifespan. Int J Sex Health. 2008; 20: 200-211. DOI: 10.1080/19317610802240170.

35. McLaren L, Kuh D. Body dissatisfaction in midlife women. J Women Aging. 2004; 16: 35-54. DOI: 10.1300/J074v16n01_04.

36. Kayar R, Civelek S, Cobanoglu M, Gungor O, Catal H, Emiroglu M. Five methods of breast volume measurement: a comparative study of measurements of specimen volume in 30 mastectomy cases. Breast Cancer. 2011; 5: 43-52. DOI: 10.4137/BCBCR.S6128.

37. Bulstrode N, Bellamy E, Shrotria S. Breast volume assessment: comparing five different techniques. Breast. 2001; 10: 117-123. DOI: http://dx.doi.org/10.1054/brst.2000.0196.

38. Kovacs L, Eder M, Hollweck R, Zimmerman A, Settles M, Schneider A, et al. Comparison between breast volume measurement using 3D surface imaging and classical techniques. Breast. 2007; 16: 137-145. DOI: http://dx.doi.org/10.1016/j.breast.2006.08.001.

39. Coltman CE, McGhee DE, Steele JR. Three-dimensional scanning in women with large, ptotic breasts: implications for bra cup sizing and design. Ergonomics. 2016: 1-7. DOI: 10.1080/00140139.2016.1176258.

40. Berberoğlu Ö, Temel M, Türkmen A. Effects of reduction mammaplasty operations on the spinal column: clinical and radiological response. Aesthetic Plast Surg. 2015; 39: 514-522. DOI: 10.1007/s00266-015-0516-6.

41. Strong B, Hall-Findlay EJ. How does volume of resection relate to symptom relief for reduction mammaplasty patients? Ann Plast Surg. 2015; 75: 376-382. DOI: 10.1097/sap.0000000000000190.

42. Spector JA, Singh SP, Karp NS. Outcomes after breast reduction: does size really matter? Ann Plast Surg. 2008; 60: 505-509. DOI: 10.1097/SAP.0b013e31816f76b5.

43. Reardon R, Grogan S. Women's reasons for seeking breast reduction: a qualitative investigation. J Health Psychol. 2011; 16: 31-41. DOI: 10.1177/1359105310367531.

44. Sigurdson L, Mykhalovskiy E, Kirkland SA, Pallen A. Symptoms and related severity experienced by women with breast hypertrophy. Plast Reconstr Surg. 2007; 119: 481-486. DOI: 10.1097/01.prs.0000246407.87267.46.

45. Benditte-Klepetko H, Leisser V, Paternostro-Sluga T, Rakos M, Trattnig S, Helbich T, et al. Hypertrophy of the breast: a problem of beauty or health? J Womens Health. 2007; 16: 1062-1069. DOI: 10.1089/jwh.2006.0183.

46. Gonzalez MA, Glickman LT, Aladegbami B, Simpson R. Quality of life after breast reduction surgery: a 10-year retrospective analysis using the Breast Q questionnaire: does breast size matter? Ann Plast Surg. 2012; 69: 361-363. DOI: 10.1097/SAP.0b013e31824a218a.

47. Wood K, Cameron M, Fitzgerald K. Breast size, bra fit and thoracic spine pain in young women: A correlational study. Chiropr Osteopat. 2008; 16: 1340-1347.

48. Goulart R, Detanico D, Vasconcellos RP, Schutz G, Dos Santos S. Reduction mammoplasty improves body posture and decreases the perception of pain. Can J Plast Surg. 2013; 21: 29-32.

49. Chao JD, Memmel HC, Redding JF, Egan L, Odom L, Casas L. Reduction mammaplasty is a functional operation, improving quality of life in symptomatic women: a prospective, single-center breast reduction outcome study. Plast Reconstr Surg. 2002; 110: 1644-1652. DOI: 10.1097/01.Prs.0000033029.01084.57.

50. Findikcioglu K, Findikcioglu F, Bulam H, Sezgin B, Ozmen S. The impact of breast reduction surgery on the vertebral column. Ann Plast Surg. 2013; 70: 639-642. DOI: 10.1097/SAP.0b013e31823fac41.

51. Karabekmez FE, Gokkaya A, Isik C, Saglam I, Efeoglu F, Gorgu M. Does reduction mammaplasty revert skeletal disturbances in the vertebral column of patients with macromastia? A preliminary study. Aesthetic Plast Surg. 2014; 38: 104-112. DOI: 10.1007/s00266-013-0194-1.

52. Karaaslan O, Demirkiran HG, Silistreli O, Sonmez E, Bedir Y, Can M, et al. The effect of reduction mammaplasty on the vertebral column: a radiologic study. TheScientificWorldJournal. 2013; 701391. DOI: 10.1155/2013/701391.

53. Findikcioglu K, Findikcioglu F, Ozmen S, Guclu T. The impact of breast size on the vertebral column: A radiologic study. Aesthetic Plast Surg. 2007; 31: 23-27.

54. McGhee D, Ramsay L, Coltman CE, Gho S, Steel J. Bra band size measurements derived from three-dimensional scans are not accurate in women with large, ptotic breasts. Ergonomics. 2018; 61: 464-472. DOI: 10.1080/00140139.2017.1349936.

55. Schinkel-Ivy A, Drake JD. Breast size impacts spine motion and postural muscle activation. J Back Musculoskelet Rehabil. 2016; 29: 741-748. DOI: 10.3233/bmr-160680.

56. Coltman KA, McGhee DE, Riddiford-Harland DL, Steele J. Does breast size affect posture? Abstracts of the XXIV Congress of the Int Soc Biomech August 4-9, 2013. In: XXIV Congress Int Soc Biomech. August 4-9, 2013 Natal Brazil, 2013.

57. Hansraj KK. Breast Forces on the Spine. Surg Technol Int. 2016; 28: 311-315.

58. Dafydd H, Roehl KR, Phillips LG, Dancey A, Peart F, Shorkrollahi K. . Redefining gigantomastia. J Plast Reconstr Aesthet Surg. 2011; 64: 160-163. DOI: 10.1016/j.bjps.2010.04.043.

59. Greendale GA, Nili NS, Huang MH, Seeger L, Karlmangla A. The reliability and validity of three non-radiological measures of thoracic kyphosis and their relations to the standing radiological Cobb angle. Osteoporos Int. 2011; 22: 1897-1905. DOI: 10.1007/s00198-010-1422-z.

60. Fortin C, Feldman DE, Cheriet F, Labelle H. Clinical methods for quantifying body segment posture: a literature review. Disabil Rehabil. 2011; 33: 367-383. DOI: 10.3109/09638288.2010.492066.

61. Azadinia F, Kamyab M, Behtash H, Saleh Ganjavian M, Javaheri M. The validity and reliability of noninvasive methods for measuring kyphosis. J Spinal Disord Tech. 2014; 27: E212-218. DOI: 10.1097/BSD.0b013e31829a3574.

62. Barrett E, McCreesh K, Lewis J. Reliability and validity of non-radiographic methods of thoracic kyphosis measurement: A systematic review. Man Ther. 2014; 19: 10-17. DOI: https://doi.org/10.1016/j.math.2013.09.003.

63. Tran TH, Wing D, Davis A, Bergstrom J, Schousboe J, Nichols J, et al. Correlations among four measures of thoracic kyphosis in older adults. Osteoporos Int. 2016; 27: 1255-1259. DOI: 10.1007/s00198-015-3368-7.

64. Barrett E, Lenehan B, O'Sullivan K, Lewis J, McCreesh K. Validation of the manual inclinometer and flexicurve for the measurement of thoracic kyphosis. Physiother theory Pract. 2018; 34: 301-308. DOI: 10.1080/09593985.2017.1394411.

65. Lapid O, de Groof EJ, Corion LU, Smeulders M, van der Horst C. The effect of breast hypertrophy on patient posture. Arch Plast Surg. 2013; 40: 559-563. DOI: 10.5999/aps.2013.40.5.559.

66. Mazzocchi M, Dessy LA, Ronza SD, Iodice P, Saggini R, Scuderi N. A study of postural changes after breast reduction. Aesthet Plast Surg. 2012; 36: 1311-1319. DOI: 10.1007/s00266-012-9968-0.

67. Sahin I, Iskender S, Ozturk S, Balaban B, Isik S. Evaluation of breast reduction surgery effect on body posture and gait pattern using three-dimensional gait analysis. Aesthet Plast Surg. 2013; 37: 549-553. DOI: 10.1007/s00266-013-0102-8.

68. Briggs A, van Dieën JH, Wrigley TV, Greig A, Phillips B, Lo S, et al. Thoracic kyphosis affects spinal loads and trunk muscle force. Phys Ther. 2007; 87: 595-607. DOI: 10.2522/ptj.20060119.

69. Mizgala CL, MacKenzie KM. Breast reduction outcome study. Ann Plast Surg. 2000; 44: 125-133. DOI: 10.1097/00000637-200044020-00001.

70. Collins ED, Kerrigan CL, Kim M, Lowrey J, Striplin D, Cunnigham B, et al. The effectiveness of surgical and nonsurgical interventions in relieving the symptoms of macromastia. Plast Reconstr Surg. 2002; 109: 1556-1566.

71. Hermans BJ, Boeckx WD, De Lorenzi F, van der Hulst R. Quality of life after breast reduction. Ann Plast Surg. 2005; 55: 227-231.

72. Perez-Panzano E, Guemes-Sanchez A, Gascon-Catalan A. Quality of life following symptomatic macromastia surgery: short- and long-term evaluation. Breast J. 2016; 22: 397-406. DOI: 10.1111/tbj.12589.

73. Cabral IV, da Silva Garcia E, Sobrinho RN, Pinto N, Juliano Y, Veiga-Filho J, et al. Use of the BREAST-Q survey in the prospective evaluation of reduction mammaplasty outcomes. Aesthet Plast Surg. 2017. DOI: 10.1007/s00266-017-1009-6.

74. Saariniemi KM, Keranen UH, Salminen-Peltola PK, Kuokkanen H. Reduction mammaplasty is effective treatment according to two quality of life instruments. A prospective randomised clinical trial. J Plast Reconstr Aesthet Surg. 2008; 61: 1472-1478. DOI: 10.1016/j.bjps.2007.09.024.

75. Fonseca CC, Veiga DF, Garcia EDS, Cabral I, De Carvalho M, De Brito M, et al. Breast hypertrophy, reduction mammaplasty, and body image. Aesthet Surg J. 2018; 38: 972-979. DOI: 10.1093/asj/sjx271.

76. Coriddi M, Nadeau M, Taghizadeh M, Taylor A. Analysis of satisfaction and well-being following breast reduction using a validated survey instrument: the BREAST-Q. Plast Reconstr Surg. 2013; 132: 285-290. DOI: 10.1097/PRS.0b013e31829587b5.

77. Saariniemi KM, Joukamaa M, Raitasalo R, Kuokkanen H. Breast reduction alleviates depression and anxiety and restores self-esteem: a prospective randomised clinical trial. Scand J Plast Reconstr Surg Hand Surg. 2009; 43: 320-324. DOI: 10.1080/02844310903258910.

78. Perez-Panzano E, Gascon-Catalan A, Sousa-Dominguez R, Carrera-Lasfuentes P, Garcia-Campayo J, Guemes-Sanchez A. Reduction mammaplasty improves levels of anxiety, depression and body image satisfaction in patients with symptomatic macromastia in the short and long term. J Psychosom Obstet Gynaecol. 2017; 38: 268-275. DOI: 10.1080/0167482x.2016.1270936.

79. Saariniemi KM, Kuokkanen HO, Tukiainen EJ. The outcome of reduction mammaplasty remains stable at 2-5 years' follow-up: a prospective study. J Plast Reconstr Aesthet Surg. 2011; 64: 573-576. DOI: 10.1016/j.bjps.2010.09.010.

80. Saleem L, John JR. Unfavourable results following reduction mammoplasty. Indian J Plast Surg. 2013; 46: 401-407. DOI: 10.4103/0970-0358.118620.

81. Saariniemi K, Luukkala T, Kuokkanen H. The outcome of reduction mammaplasty is affected more by psychosocial factors than by changes in breast dimensions. Scand J Surg. 2011; 100: 105-109. DOI: 10.1177/145749691110000207.

82. Milne JS, Lauder IJ. Age effects in kyphosis and lordosis in adults. Ann Hum biol. 1974; 1: 327-337.

83. Ettinger B, Black DM, Palermo L, Nevitt M, Melinkoff S, Cummings S. Kyphosis in older women and its relation to back pain, disability and osteopenia: the study of osteoporotic fractures. Osteoporos Int. 1994; 4: 55-60.

84. Ota S, Goto H, Noda Y, Fujita R, Matsui Y. Relationship between standing postural alignments and physical function among elderly women using day service centers in Japan. J Back Musculoskelet Rehabil. 2015; 28: 111-117. DOI: 10.3233/bmr-140498.

85. Greig AM, Briggs AM, Bennell KL, Hodges P. Trunk muscle activity is modified in osteoporotic vertebral fracture and thoracic kyphosis with potential consequences for vertebral health. PLoS One. 2014; 9: e109515. DOI: 10.1371/journal.pone.0109515.

86. Finkelstein JS, Brockwell SE, Mehta V, Greendale G, Sowers M, Ettinger B, et al. Bone mineral density changes during the menopause transition in a multiethnic cohort of women. J Clin Endocrinol Metab. 2008; 93: 861-868. DOI: 10.1210/jc.2007-1876.

87. O'Neill TW. The Relationship Between Bone Density and Incident Vertebral Fracture in Men and Women. J Bone Miner Res. 2009; 17: 2214-2221. DOI: 10.1359/jbmr.2002.17.12.2214.

88. Anagnostis P, Siolos P, Gkekas NK, Kosmidou N, Artzouchaltzi A, Chrisou K, et al. Association between age at menopause and fracture risk: a systematic review and meta-analysis. Endocrine. 2018. DOI: 10.1007/s12020-018-1746-6.

89. Eastell R, Cedel SL, Wahner HW, Riggs B, Melton LJ. Classification of vertebral fractures. J Bone Mineral Res. 1991; 6: 207-215. DOI: 10.1002/jbmr.5650060302.

90. Nevitt MC, Ettinger B, Black DM, Stone K, Jamal S, Ensrud K, et al. The association of radiographically detected vertebral fractures with back pain and function: a prospective study. Ann Intern Med. 1998; 128: 793-800.

91. Milne JS, Lauder IJ. The relationship of kyphosis to the shape of vertebral bodies. Ann Hum Biol. 1976; 3: 173-179.

92. Horii C, Asai Y, Iidaka T, Muraki S, Oka H, Tsutsui S, et al. Differences in prevalence and associated factors between mild and severe vertebral fractures in Japanese men and women: the third survey of the ROAD study. J Bone Miner Metab. 2019. DOI: 10.1007/s00774-018-0981-5.

93. Abdel-Hamid Osman A, Bassiouni H, Koutri R, Nijs J, Geusens P, Dequecker J. Aging of the thoracic spine: distinction between wedging in osteoarthritis and fracture in osteoporosis--a cross-sectional and longitudinal study. Bone. 1994; 15: 437-442.

94. Johansson L, Sundh D, Nilsson M, Mellstrom D, Lorentzon M. Vertebral fractures and their association with health-related quality of life, back pain and physical function in older women. Osteoporos Int. 2018; 29: 89-99. DOI: 10.1007/s00198-017-4296-5.

95. Kanis JA, Johansson H, Oden A, McCloskey E. Assessment of fracture risk. Eur J Radiol. 2009; 71: 392-397. DOI: 10.1016/j.ejrad.2008.04.061.

96. Ahmadi SA, Takahashi S, Hoshino M, Takayama K, Sasaoka R, Tsujio T, et al. Association between MRI findings and back pain after osteoporotic vertebral fractures: a multicenter prospective cohort study. Spine J. 2019. DOI: 10.1016/j.spinee.2019.02.007.

97. Delmas PD, van de Langerijt L, Watts NB, Eastell R, Genant H, Grauer A, et al. Underdiagnosis of vertebral fractures is a worldwide problem: the IMPACT study. J Bone Miner Res. 2005; 20: 557-563. DOI: 10.1359/jbmr.041214.

98. Edmondston S, Waller R, Vallin P, Holthe A, Noebauer A, King, E. Thoracic spine extension mobility in young adults: influence of subject position and spinal curvature. J Orthop Sports Phys Ther. 2011; 41: 266-273. DOI: 10.2519/jospt.2011.3456.

99. Kuo YL, Tully EA, Galea MP. Video based measurement of sagittal range of spinal motion in young and older adults. Man Ther. 2009; 14: 618-622. DOI: 10.1016/j.math.2008.12.006.

100. Edmondston SJ, Christensen MM, Keller S, Steigen S, Barclay L. Functional radiographic analysis of thoracic spine extension motion in asymptomatic men. J Manipulative Physiol Ther. 2012; 35: 203-208. DOI: http://dx.doi.org/10.1016/j.jmpt.2012.01.008.

101. Edmondston S, Ferguson A, Ippersiel P, Ronningen L, Sodeland S, Barclay L. Clinical and radiological investigation of thoracic spine extension motion during bilateral arm elevation. J Orthop Sports Phys Ther. 2012; 42: 861-869. DOI: 10.2519/jospt.2012.4164.

102. Miyakoshi N, Hongo M, Maekawa S, Ishikawa Y, Shimada Y, Okada K, et al. Factors related to spinal mobility in patients with postmenopausal osteoporosis. Osteoporos Int. 2005; 16: 1871-1874. DOI: 10.1007/s00198-005-1953-x.

103. Page I, Descarreaux M. Effects of spinal manipulative therapy biomechanical parameters on clinical and biomechanical outcomes of participants with chronic thoracic pain: a randomized controlled experimental trial. BMC Musculoskelet Disord. 2019; 20: 29. DOI: 10.1186/s12891-019-2408-4.

104. Sinaki M, Nwaogwugwu NC, Phillips BE, Mokri M. Effect of gender, age, and anthropometry on axial and appendicular muscle strength. Am J Phys Med rehabil. 2001; 80: 330-338.

105. Goldspink G. Age-Related Loss of Muscle Mass and Strength. J Aging Res. 2012; 158279. DOI: 10.1155/2012/158279.

106. von Haehling S, Morley JE, Anker SD. An overview of sarcopenia: facts and numbers on prevalence and clinical impact. J Cachexia Sarcopenia Muscle. 2010; 1: 129-133. DOI: 10.1007/s13539-010-0014-2.

107. Johannesdottir F, Allaire B, Anderson DE, Samelson E, Kiel D, Bouxsein M. Population-based study of age- and sex-related differences in muscle density and size in thoracic and lumbar spine: the Framingham study. Osteoporos Int. 2018. DOI: 10.1007/s00198-018-4490-0.

108. Schwartz AV, Newman AB, Goodpaster BH, Simonsick E, Tylasky F, Visser M, et al. The loss of skeletal muscle strength, mass, and quality in older adults: the health, aging and body composition study. J Gerontol. 2006; 61: 1059-1064. DOI: 10.1093/gerona/61.10.1059.

109. Visser M, Pahor M, Tylavsky F, Kritchevsky S, Cauley J, Newman A, et al. One- and two-year change in body composition as measured by DXA in a population-based cohort of older men and women. J Appl physiol. 2003; 94: 2368-2374. DOI: 10.1152/japplphysiol.00124.2002.

110. Mika A, Unnithan VB, Mika P. Differences in thoracic kyphosis and in back muscle strength in women with bone loss due to osteoporosis. Spine. 2005; 30: 241-246.

111. Sinaki M, Wollan PC, Scott RW, Gelczer R. Can strong back extensors prevent vertebral fractures in women with osteoporosis? Mayo Clin Proc. 1996; 71: 951-956. DOI: 10.1016/s0025-6196(11)63768-3.

112. Yamamoto J, Bergstrom J, Davis A, Wing D, Schousboe J, Nichols J, et al. Trunk lean mass and its association with 4 different measures of thoracic kyphosis in older community dwelling persons. PLoS One. 2017; 12: e0174710. DOI: 10.1371/journal.pone.0174710.

113. Sinaki M, Itoi E, Wahner HW, Wollan P, Gelzcer R, Mullan B, et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone. 2002; 30: 836-841.

114. Neumann DA. Kinesiology of the musculoskeletal system : foundations for rehabilitation. St. Louis, Mo: Mosby/Elsevier; 2010.

115. McIntosh G, Wilson L, Affieck M, Hall H. Trunk and lower extremity muscle endurance: normative data for adults. J Rehabil Outcome Meas. 1998; 2: 20-39.

116. Mannion AF, Dumas GA, Cooper RG, Espinosa F, Faris M, Stevenson J. Muscle fibre size and type distribution in thoracic and lumbar regions of erector spinae in healthy subjects without low back pain: normal values and sex differences. J Anat. 1997; 190: 505-513.

117. O'Sullivan PB, Mitchell T, Bulich P, Waller R, Holte J. The relationship beween posture and back muscle endurance in industrial workers with flexion-related low back pain. Man Ther. 2006; 11: 264-271. DOI: 10.1016/j.math.2005.04.004.

118. Smith A, Beales D, O'Sullivan P, Bear N, Straker L. Low back pain with impact at 17 years of age is predicted by early adolescent risk factors from multiple domains: analysis of the Western Australian pregnancy cohort (Raine) study. J Orthop Sports Phys Ther. 2017; 47: 752-762. DOI: 10.2519/jospt.2017.7464.

119. Shahidi B, Curran-Everett D, Maluf KS. Psychosocial, physical, and neurophysiological risk factors for chronic neck pain: A Prospective Inception Cohort Study. J pain. 2015; 16: 1288-1299. DOI: 10.1016/j.jpain.2015.09.002.

120. Smuck M, Kao MC, Brar N, Martinez-Ith A, Choi J, Tomkins-Lane C. Does physical activity influence the relationship between low back pain and obesity? Spine J. 2014; 14: 209-216. DOI: 10.1016/j.spinee.2013.11.010.

121. Webb R, Brammah T, Lunt M, Urmin M, Allison T, Symmons D. Prevalence and predictors of intense, chronic, and disabling neck and back pain in the UK general population. Spine. 2003; 28: 1195-1202. DOI: 10.1097/01.Brs.0000067430.49169.01.

122. Peeters GMEE, Pisters M, Mishra GD, Brown WJ. The influence of long-term exposure and timing of physical activity on new joint pain and stiffness in mid-age women. Osteoarthr Cartilage. 2014. DOI: http://dx.doi.org/10.1016/j.joca.2014.06.040.

123. Dontje ML, Krijnen WP, de Greef MH, Peeters G, Stolk R, van der Schans C, et al. Effect of diagnosis with a chronic disease on physical activity behavior in middle-aged women. Prev Med. 2016; 83: 56-62. DOI: 10.1016/j.ypmed.2015.11.030.

124. Adamson L BW, Byles J, Chojenta C, Dobson A, Fitzgerald D, Hockey R, et al. Women's weight: Findings from the Australian longitudinal study on women's health. Australian Government Department of Health and Ageing 2007 [cited 2016 Dec 16]. Available from: https://www.alswh.org.au/images/content/pdf/major_reports/2007_major_report_b.pdf.

125. Hill E, Hodge A, Clifton P, Shivappa N, Herbert J, Dennerstein L, et al. Longitudinal nutritional changes in aging Australian women. Asia Pac J Clin Nutr. 2019; 28: 139-149. DOI: 10.6133/apjcn.201903_28(1).0019.

126. Yu PA, Hsu WH, Hsu WB, Kuo LT, Lin ZR, Shen WJ,et al. The effects of high impact exercise intervention on bone mineral density, physical fitness, and quality of life in postmenopausal women with osteopenia: A retrospective cohort study. Medicine. 2019; 98: e14898. DOI: 10.1097/md.0000000000014898.

127. Steele JR, Coltman CE, McGhee DE. Effects of obesity on breast size, thoracic spine structure and function, upper torso musculoskeletal pain and physical activity in women. J Sport Health Sci. 2019. DOI: https://doi.org/10.1016/j.jshs.2019.05.003.

128. Linton SJ, Shaw WS. Impact of psychological factors in the experience of pain. Phys Ther. 2011; 91: 700-711. DOI: 10.2522/ptj.20100330.

129. Hartvigsen J, Hancock MJ, Kongsted A, Louw Q, Ferreira M, Genevay S, et al. What low back pain is and why we need to pay attention. Lancet. 2018; 391: 2356-2367. DOI: 10.1016/S0140-6736(18)30480-X.

130. Linton SJ. A review of psychological risk factors in back and neck pain. Spine. 2000; 25: 1148-1156. DOI: 10.1097/00007632-200005010-00017.

131. Deeks A, McCabe MP. Menopausal stage and age and perceptions of body image. Psychol Health. 2001; 16: 367-379. DOI: 10.1080/08870440108405513.

132. Peeters G, Waller M, Dobson AJ. SF-36 normative values according to level of functioning in older women. Qual Life Res. 2019; 28: 979-989. DOI: 10.1007/s11136-018-2077-z.

133. Ware JE, Kosinski M, Dewey JE. How to Score Version 2 of the SF-36 Health Survey. Lincoln, RI: QualityMetric Incorporated, 2000.

134. Pusic AL, Klassen AF, Scott AM, Klok J, Cordeiro P, Cano S. Development of a new patient-reported outcome measure for breast surgery: the BREAST-Q. Plast Reconstr Surg. 2009; 124: 345-353. DOI: 10.1097/PRS.0b013e3181aee807.

135. Husky MM, Ferdous Farin F, Compagnone P, Fermanian C, Kovess-Masfety V. Chronic back pain and its association with quality of life in a large French population survey. Health Qual Life Outcomes. 2018; 16: 195. DOI: 10.1186/s12955-018-1018-4.

136. Ludwig C, Luthy C, Allaz AF, Hermann F, Cedraschi C. The impact of low back pain on health-related quality of life in old age: results from a survey of a large sample of Swiss elders living in the community. Eur Spine J. 2018; 27: 1157-1165. DOI: 10.1007/s00586-017-5427-6.

137. Cedraschi C, Luthy C, Allaz AF, Hermann F, Ludwig C. Low back pain and health-related quality of life in community-dwelling older adults. Eur Spine J. 2016; 25: 2822-2832. DOI: 10.1007/s00586-016-4483-7.

138. Levenig CG, Kellmann M, Kleinert J, Belz J, Hesserlmann T, Hasenbring M. Body image is more negative in patients with chronic low back pain than in patients with subacute low back pain and healthy controls. Scand J Pain. 2019; 19: 147-156. DOI: 10.1515/sjpain-2018-0104.

139. Coltman CE, Steele JR, McGhee DE. Does breast size affect how women participate in physical activity? J Sci Med Sport. 2018. DOI: 10.1016/j.jsams.2018.09.226.

140. Greenbaum AR, Heslop T, Morris J, Dunn K. An investigation of the suitability of bra fit in women referred for reduction mammaplasty. Brit J Plast Surg. 2003; 56: 230-236. DOI: http://dx.doi.org/10.1016/S0007-1226(03)00122-X.

141. McGhee D, Steele JR. Optimising breast support in female patients through correct bra fit. A cross-sectional study. J Sci Med Sport. 2010; 13: 568-572. DOI: http://dx.doi.org/10.1016/j.jsams.2010.03.003.

142. Ryan EL. Pectoral girdle myalgia in women: a 5-year study in a clinical setting. Clin J Pain. 2000; 16: 298-303. 2001/01/12.

143. White J, Scurr J. Evaluation of professional bra fitting criteria for bra selection and fitting in the UK. Ergonomics. 2012; 55: 704-711. DOI: 10.1080/00140139.2011.647096.

144. Coltman CE, Steele JR, McGhee DE. Which bra components contribute to incorrect bra fit in women across a range of breast sizes? Cloth Textiles Res J. 2017; 36: 78-90. DOI: 10.1177/0887302X17743814.

145. Balogh M, Gellen C. Community Radio National Listender Survey 2018. Crows Nest, NSW: McNair YellowSquares. 2018 [cited 2019 Jan 16]. Available at: https://www.cbaa.org.au/sites/default/files/media/McNair%20yellowSquares%20-%20NLS%20-%20Main%20Report%202018%20-%20FINAL-nopg13.pdf

146. Australian Bureau of Statistics. Western Australia: Population Statistics 2013. Canberra (Australia): Australian Bureau of Statistics, 2014 [cited 2016 Oct 11]. Available from: http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/3222.0main+features52012%20(base)%20to%202101.

147. Faul F, Erdfelder E, Buchner A, Lang A. Statistical power analyses using G*Power 3.1: tests for correlation and regression analyses. Beh Res Methods. 2009; 41: 1149-1160. DOI: 10.3758/brm.41.4.1149.

148. Harlow SD, Gass M, Hall JE, Lobo R, Maki P, Rebar R, et al. Executive summary of the stages of reproductive aging workshop +10: addressing the unfinished agenda of staging reproductive aging. Climacteric. 2012; 15: 105-114. DOI: 10.3109/13697137.2011.650656.

149. Dionne CE, Dunn KM, Croft PR, Nachemerson A, Buchbinder R, Walker B, et al. A consensus approach toward the standardization of back pain definitions for use in prevalence studies. Spine. 2008; 33: 95-103. DOI: 10.1097/BRS.0b013e31815e7f94.

150. Norquist JM, Girman C, Fehnel S, DeMuro-Mercon C, Santanello N. Choice of recall period for patient-reported outcome (PRO) measures: criteria for consideration. Qual Life Res. 2012; 21: 1013-1020. DOI: 10.1007/s11136-011-0003-8.

151. Ferreira-Valente MA, Pais-Ribeiro JL, Jensen MP. Validity of four pain intensity rating scales. Pain. 2011; 152: 2399-2404. DOI: 10.1016/j.pain.2011.07.005.

152. Boonstra AM, Stewart RE, Köke AJA, Oosterwijke R, Swaan J, Schreurs K, et al. Cut-Off points for mild, moderate, and severe pain on the numeric rating scale for pain in patients with chronic musculoskeletal pain: variability and influence of sex and catastrophizing. Front Psychol. 2016; 7: 1466-1466. DOI: 10.3389/fpsyg.2016.01466.

153. Bolton JE, Wilkinson RC. Responsiveness of pain scales: a comparison of three pain intensity measures in chiropractic patients. J Manipulative Physiol Ther. 1998; 21: 1-7.

154. Breivik EK, Bjornsson GA, Skovlund E. A comparison of pain rating scales by sampling from clinical trial data. Clin J Pain. 2000; 16: 22-28.

155. Farrar JT, Young JP, LaMoreaux L, Werth J, Poole, R. Clinical importance of changes in chronic pain intensity measured on an 11-point numerical pain rating scale. Pain. 2001; 94: 149-158. DOI: 10.1016/S0304-3959(01)00349-9.

156. McGhee D, Steele J. How do respiratory state and measurement method affect bra size calculations? Brit J Sports Med. 2006; 40: 970-974.

157. McGhee DE, Steele J. Breast volume and bra size. Int J Cloth Sci Technol. 2011; 23: 351-360. DOI: 10.1108/09556221111166284.

158. Choppin S, Wheat J, Gee M, Goyal A. The accuracy of breast volume measreuemnt methods: A systematic review. Breast; 28: 121-9. DOI: 10.1016/j.breast.2016.05.010

159. Ameona. Breast Form Fitting Guide; 2015 [cited 2015 Aug 29]. Available from: http://www.amoena.com/au/about-us/breast-form-fitting-guide.

160. Koff E, Benavage A. Breast size perception and satisfaction, body image, and psychological functioning in caucasian and Asian American college Women. Sex Roles. 1998; 38: 655-673. DOI: 10.1023/a:1018802928210.

161. Lagendijk M, van Egdom LSE, Richel C, van Leeuwen N, Verhoef C, Lingsma H, et al. Patient reported outcome measures in breast cancer patients. Eur J Surg Oncol. 2018; 44: 963-968. DOI: 10.1016/j.ejso.2018.03.009.

162. Cano SJ, Klassen AF, Scott AM, Cordeiro P, Pusic A. The BREAST-Q: further validation in independent clinical samples. Plast Reconstr Surg. 2012; 129: 293-302. DOI: 10.1097/PRS.0b013e31823aec6b.

163. Mundy LR, Homa K, Klassen AF, Pusic A, Kerrigan C. Understanding the health burden of macromastia: normative data for the BREAST-Q reduction module. Plast Reconstr Surg. 2017; 139: 846e-853e. DOI: 10.1097/prs.0000000000003171.

164. Pusic AL, Cano SJ, Klassen AF. BREAST-Q User Manual 1.0. New York, NY: Mapi Research Trust, Memorial Sloan-Kettering Cancer Centre, 2012.

165. Albanes D, Conway JM, Taylor PR, Moe P, Judd J. Validation and comparison of eight physical activity questionnaires. Epidemiol. 1990; 1: 65-71.

166. Prince SA, Adamo KB, Hamel ME, Hardt j, Connor Gorber S, Tremblay M. A comparison of direct versus self-report measures for assessing physical activity in adults: a systematic review. Int J Behav Nutr Phys Act. 2008; 5: 56-56. DOI: 10.1186/1479-5868-5-56.

167. Althubaiti A. Information bias in health research: definition, pitfalls, and adjustment methods. J Multidiscip Healthc. 2016; 9: 211-217. DOI: 10.2147/JMDH.S104807.

168. Hertogh E, Monninkhof E, Schouten E, Peeter P, chuit A. Validity of the Modified Baecke Questionnaire: comparison with energy expenditure according to the doubly labeled water method. Int J Behav Nutr Phys Act. 2008; 5: 1-6. DOI: 10.1186/1479-5868-5-30.

169. Fix A, Daughton D. Human Activity Profile: Professional Manual. Odessa, FL: Psychological Assessment Resources Inc., 1988.

170. Bennell KL, Hinman RS, Crossley KM, Metcalf B, Buchbinder R, Greeen S, et al. Is the Human Activity Profile a useful measure in people with knee osteoarthritis? J Rehabil Res Dev. 2004; 41: 621-630.

171. Davidson M, de Morton N. A systematic review of the Human Activity Profile. Clinical Rehabil. 2007; 21: 151-162. DOI: 10.1177/0269215506069475.

172. Hernanz F, Fidalgo M, Muñoz P, Noriega M, Gomez-Fleitas M. Impact of reduction mammoplasty on the quality of life of obese patients suffering from symptomatic macromastia: A descriptive cohort study. J Plast Reconstr Aesthet Surg. 2016; 69: e168-e173. DOI: 10.1016/j.bjps.2016.05.012.

173. McCallum J. The SF-36 in an Australian sample: validating a new, generic health status measure. Aust Public Health. 1995; 19: 160-166.

174. McHorney CA, Ware JE, Raczek AE. The MOS 36-Item Short-Form Health Survey (SF-36): II. Psychometric and clinical tests of validity in measuring physical and mental health constructs. Med Care. 1993; 31: 247-263.

175. Jenkinson C, Stewart-Brown S, Petersen S, Paice C. Assessment of the SF-36 version 2 in the United Kingdom. J Epidemiol Community Health. 1999; 53: 46-50.

176. Mishra G, Schofield M. Norms for the physical and mental health component summary scores of the SF36 for young, middle-aged and older Australian women. Qual Life Res; 1998, 7:215-220. DOI:10.1023/A:1024917510063

177. Ware JE, Sherbourne CD. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med care. 1992; 30: 473-483.

178. Samsa G, Edelman D, Rothman ML, Williams G, Lipscomb J, Matchar D. Determining clinically important differences in health status measures: A general approach with illustration to the Health Utilities Index Mark II. Pharmacoeconomics. 1999; 15: 141-155. DOI: 10.2165/00019053-199915020-00003.

179. Hays RD, Woolley JM. The concept of clinically meaningful difference in health-related quality-of-life research. How meaningful is it? Pharmacoeconomics 2000; 18: 419-423. DOI: 10.2165/00019053-200018050-00001.

180. Patrick DL, Deyo RA. Generic and disease-specific measures in assessing health status and quality of life. Med Care. 1989; 27: S217-232.

181. Cohen WA, Mundy LR, Ballard TNS, Klassen A, Cano S, Brown J, et al. The BREAST-Q in surgical research: A review of the literature 2009-2015. J Plast Reconstr Aesthet Surg. 2016; 69: 149-162. DOI: 10.1016/j.bjps.2015.11.013.

182. Cano SJ, Klassen AF, Scott A, Alderman A, Pusic A. Interpreting clinical differences in BREAST-Q scores: minimal important difference. Plast Reconstr Surg. 2014; 134: 173e-175e. DOI: 10.1097/prs.0000000000000267.

183. Garner DM, Olmstead MP, Polivy J. Development and validation of a multidimensional eating disorder inventory for anorexia nervosa and bulimia. Int J Eat Disord. 1983; 2: 15-34. DOI: 10.1002/1098-108X(198321)2:2<15::AID-EAT2260020203>3.0.CO;2-6.

184. Rosen JC, Jones A, Ramirez E, Waxman S. Body Shape Questionnaire: studies of validity and reliability. Int J Eat Disord. 1996; 20: 315-319. DOI: 10.1002/(sici)1098-108x(199611)20:3<315::Aid-eat11>3.0.Co;2-z.

185. Avalos L, Tylka TL, Wood-Barcalow N. The Body Appreciation Scale: Development and psychometric evaluation. Body Image. 2005; 2: 285-297. DOI: 10.1016/j.bodyim.2005.06.002.

186. Slade PD, Dewey ME, Newton T, Brodie D, Kiemle, G. Development and preliminary validation of the body satisfaction scale (BSS). Psychol Health. 1990; 4: 213-220. DOI: 10.1080/08870449008400391.

187. Vernon H, Mior S. The Neck Disability Index: a study of reliability and validity. J Manipulative Physiol Ther. 1991; 14: 409-415.

188. MacDermid JC, Walton DM, Avery S, Blanchard A, Etruw E, McAlpine C, et al. Measurement properties of the Neck Disability Index: A systematic review. J Orthop Sports Phys Ther. 2009; 39: 400-417. DOI: 10.2519/jospt.2009.2930.

189. Vernon H. The Neck Disability Index: state-of-the-art, 1991-2008. J Manipulative Physiol Ther. 2008; 31: 491-502. DOI: 10.1016/j.jmpt.2008.08.006.

190. Kato S, Takeshita K, Matsudaira K, Tonousu J, Hara N, Chikuda H. Normative score and cut-off value of the Neck Disability Index. J Orthop Sci. 2012; 17: 687-693. DOI: 10.1007/s00776-012-0276-y.

191. Stratford P, Gill C, Westaway M, Binkley J. Assessing disability and change on individual patients: A report of a patient specific measure. Physiother Can. 1995; 47: 258-263. DOI: 10.3138/ptc.47.4.258.

192. Fairbank JC, Pynsent PB. The Oswestry Disability Index. Spine. 2000; 25: 2940-2952.

193. Wright RW, Baumgarten KM. Shoulder outcomes measures. J Am Acad Orthop Surg. 2010; 18: 436-444.

194. Lheureux A, Berquin A. Comparison between the STarT Back Screening Tool and the Orebro Musculoskeletal Pain Screening Questionnaire: which tool for what purpose? A semi-systematic review. Ann Phys Rehabil Med. 2019; 62: 178-188. DOI: 10.1016/j.rehab.2018.09.007.

195. Linton SJ, Nicholas M, MacDonald S. Development of a short form of the Orebro musculoskeletal pain screening questionnaire. Spine. 2011; 36: 1891-1895. DOI: 10.1097/BRS.0b013e3181f8f775.

196. Cabral IV, da Silva Garcia E, Sobrinho RN, Sobrinho R, Pinto N, Juliano Y, et al. Use of the BREAST-Q Survey in the Prospective Evaluation of Reduction Mammaplasty Outcomes. Aesthet Plast Surg. 2018; 42: 388-395. DOI: 10.1007/s00266-017-1009-6.

197. Kanis JA, Adachi JD, Cooper C, Clark P, Cummings s, Diaz-Curiel M, et al. Standardising the descriptive epidemiology of osteoporosis: recommendations from the Epidemiology and Quality of Life Working Group of IOF. Osteoporos Int. 2013; 24: 2763-2764. DOI: 10.1007/s00198-013-2413-7.

198. Lorente Ramos RM, Azpeitia Arman J, Arevalo Galeano N, Munoz Hernandez A, Garcia Gomez J, et al. Dual energy X-ray absorptimetry: fundamentals, methodology, and clinical applications. Radiol. 2012; 54: 410-423. DOI: 10.1016/j.rx.2011.09.023.

199. Albanese CV, Diessel E, Genant HK. Clinical applications of body composition measurements using DXA. J Clin densitom. 2003; 6: 75-85..

200. Damilakis J, Adams JE, Guglielmi G, Link T. Radiation exposure in X-ray-based imaging techniques used in osteoporosis. Eur Radiol. 2010; 20: 2707-2714. DOI: 10.1007/s00330-010-1845-0.

201. Kanis JA, McCloskey EV, Harvey NC, Johansson H, Leslie W. Intervention thresholds and the diagnosis of osteoporosis. J Bone Miner Res. 2015; 30: 1747-1753. DOI: 10.1002/jbmr.2531.

202. Kanis JA, Melton LJ, Christiansen C, Johnston C, Nikolai K. The diagnosis of osteoporosis. J Bone Miner Res. 1994; 9: 1137-1141. DOI: 10.1002/jbmr.5650090802.

203. Peacock DJ, Egger P, Taylor P, Cawley M, Cooper C. Lateral bone density measurements in osteoarthritis of the lumbar spine. Ann Rheum Dis. 1996; 55: 196-198.

204. Schorr M, Thomas JJ, Eddy KT, Dichtel L, Lawson E, Meenaghan E, et al. Bone density, body composition, and psychopathology of anorexia nervosa spectrum disorders in DSM-IV vs DSM-5. Int J Eat Disord. 2017; 50: 343-351. DOI: 10.1002/eat.22603.

205. Buzga M, Holeczy P, Svagera Z, Svorc P, Zavadilova V. Effects of sleeve gastrectomy on parameters of lipid and glucose metabolism in obese women - 6 months after operation. Wideochir Inne Tech Maloinwazyjne. 2013; 8: 22-28. DOI: 10.5114/wiitm.2011.31631.

206. Zheng R, Yu W, Fan J. Breast measurement and sizing. In: Yu W, Fan J, Harlock SC, et al. (editors). Innovation and Technology of Women's Intimate Apparel. Woodhead Publishing, 2006, pp.28-58.

207. Bayer CM, Bani MR, Schneider M, Dammer U, Raabe E, Haeberle L, et al. Assessment of breast volume changes during human pregnancy using a three-dimensional surface assessment technique in the prospective CGATE study. EurJ Cancer Prev. 2014; 23: 151-157. DOI: 10.1097/CEJ.0b013e3283651ccb.

208. McGhee D, Steele JR, Zealey WJ, Dakacs G. Bra–breast forces generated in women with large breasts while standing and during treadmill running: Implications for sports bra design. Appl Ergon. 2013; 44: 112-118. DOI: 10.1016/j.apergo.2012.05.006.

209. Katch VL, Campaigne B, Freedson P, Sady S, Katch F, Behnke A. Contribution of breast volume and weight to body fat distribution in females. Am J Phys Anthropol. 1980; 53: 93-100. DOI: 10.1002/ajpa.1330530113.

210. Smith DJ, Palin WE, Katch VL, Bennett JE. Breast volume and anthropomorphic measurements: normal values. Plast Reconstr Surg. 1986; 78: 331-335.

211. Qiao Q, Zhou G, Ling Y. Breast Volume Measurement in Young Chinese Women and Clinical Applications. Aesthet Plast Surg. 1997; 21: 362-368. DOI: 10.1007/s002669900139.

212. Fujii T, Yamaguchi S, Yajima R, Tdutsumi S, Asao T, Kuwano H. Accurate assessment of breast volume by computed tomography using three-dimensional imaging device. Am Surg 2012; 78: 933-935.

213. Yip JM, Mouratova N, Jeffery RM, Veitch D, Woodman R, Dean N. Accurate assessment of breast volume: a study comparing the volumetric gold standard (direct water displacement measurement of mastectomy specimen) with a 3D laser scanning technique. Ann Plast Surg. 2012; 68: 135-141. DOI: 10.1097/SAP.0b013e31820ebdd0.

214. Xi W, Perdanasari AT, Ong Y, Han S, Min P, Su P, et al. Objective breast volume, shape and surface area assessment: a systematic review of breast measurement methods. Aesthet Plast Surg. 2014; 38: 1116-1130. DOI: 10.1007/s00266-014-0412-5.

215. Chae MP, Rozen WM, Spychal RT, Hunter-Smith D. Breast volumetric analysis for aesthetic planning in breast reconstruction: a literature review of techniques. Gland Surg. 2016; 5: 212-226. DOI: 10.3978/j.issn.2227-684X.2015.10.03.

216. Veitch D, Burford K, Dench P, Dean N, Griffin P. Measurement of breast volume using body scan technology (computer-aided anthropometry). Work. 2012; 41 Suppl 1: 4038-4045. DOI: 10.3233/wor-2012-0068-4038.

217. Caruso MK, Guillot TS, Nguyen T, Greenway F. The cost effectiveness of three different measures of breast volume. Aesthet Plast Surg. 2006; 30: 16-20. DOI: 10.1007/s00266-004-0105-6.

218. Berlei. Australian Bra Sizes; 2018 [cited 2018 Jan 18]. Available from: https://www.berlei.com.au/size-charts

219. Triumph International. Bras and bodysuits size chart; 2018 [cited 2018 Jan 18]. Available from: https://au.triumph.com/pages/size-charts.

220. Playtex. Bra fit guide; 2018 [cited 2018 Jan 18]. Available from: https://www.playtex.com.au/fit-guide.

221. Regnault P. Breast ptosis. Definition and treatment. Clin Plast Surg. 1976; 3: 193-203.

222. Kim MS, Reece GP, Beahm EK, Miller M, Neely Atkinson E, et al. Objective assessment of aesthetic outcomes of breast cancer treatment: Measuring ptosis from clinical photographs. Computers Biol Med. 2007; 37: 49-59. DOI: 10.1016/j.compbiomed.2005.10.007.

223. Westreich M. Anthropomorphic breast measurement: protocol and results in 50 women with aesthetically perfect breasts and clinical application. Plast reconstr Surg. 1997; 100: 468-479.

224. Brown TPLH, Ringrose C, Hyland RE, Cole A, Brotherston T. A method of assessing female breast morphometry and its clinical application. Brit J Plast Surg. 1999; 52: 355-359. DOI: 10.1054/bjps.1999.3110.

225. Coltman C, McGhee D, Steele J. Bra strap orientations and designs to minimise bra strap discomfort and pressure during sport and exercise in women with large breasts. Sports Med. 2015; 2: 5. DOI 10.1186/s40798-015-0014-z.

226. Demoulin C, Grosdent S, Smeets R, Verbunt J, Jidovtseff B, Mahieu G, et al. Muscular performance assessment of trunk extensors: A critical appraisal of the literature. Low Back Pain Intech. 2012. DOI: 10.5772/34188.

227. Demoulin C, Vanderthommen M, Duysens C, Crielaard, J. Spinal muscle evaluation using the Sorensen test: a critical appraisal of the literature. Joint Bone Spine. 2006; 73: 43-50. DOI: 10.1016/j.jbspin.2004.08.002.

228. Moreau CE, Green BN, Johnson CD, Moreau S. Isometric back extension endurance tests: a review of the literature. J Manipulative Physiol Ther. 2001; 24: 110-122.

229. Muller R, Strassle K, Wirth B. Isometric back muscle endurance: an EMG study on the criterion validity of the Ito test. J Electromyogr Kinesiol. 2010; 20: 845-850. DOI: 10.1016/j.jelekin.2010.04.004.

230. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax T. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. Arch Phys Med Rehabil. 1996; 77: 75-79.

231. Ropponen A, Gibbons LE, Videman T, Battie M. Isometric back extension endurance testing: reasons for test termination. J Orthop Sports phys Ther. 2005; 35: 437-442. DOI: 10.2519/jospt.2005.35.7.437.

232. Crawford HJ, Jull GA. The influence of thoracic posture and movement on range of arm elevation. Physiother Theory Pract. 1993; 9: 143-148. DOI: 10.3109/09593989309047453.

233. Morita D, Yukawa Y, Nakashima H, Ito K, Yoshina G, Machino M, et al. Range of motion of thoracic spine in sagittal plane. Eur Spine J. 2014; 23: 673-678. DOI: 10.1007/s00586-013-3088-7.

234. Fon GT, Pitt MJ, Thies AC. Thoracic kyphosis: range in normal subjects. Am J Roentgenol. 1980; 134: 979-983. DOI: 10.2214/ajr.134.5.979.

235. Harrison DE, Cailliet R, Harrison DD, Janik TJ, Holland B. Reliability of centroid, Cobb, and Harrison posterior tangent methods: which to choose for analysis of thoracic kyphosis. Spine. 2001; 26: E227-234.

236. Briggs A, Wrigley T, Tully E, Adams P, Greig A, Bennell, K. Radiographic measures of thoracic kyphosis in osteoporosis: Cobb and vertebral centroid angles. Skelet Radiol. 2007; 36: 761-767. DOI: 10.1007/s00256-007-0284-8.

237. de Oliveira TS, Candotti CT, La Torre M, Pelinson P, Furlanetto T, Kutchak F, et al. Validity and reproducibility of the measurements obtained using the flexicurve instrument to evaluate the angles of thoracic and lumbar curvatures of the spine in the sagittal plane. Rehabil Res Pract. 2012; 186156. DOI: 10.1155/2012/186156.

238. Genant HK, Wu CY, van Kuijk C, Nevitt MC. Vertebral fracture assessment using a semiquantitative technique. J Bone Miner Res. 1993; 8: 1137-1148. DOI: 10.1002/jbmr.5650080915.

239. Griffith JF. Identifying osteoporotic vertebral fracture. Quant Imaging Med Surg. 2015; 5: 592-602. DOI: 10.3978/j.issn.2223-4292.2015.08.01.

240. McCloskey EV, Spector TD, Eyres KS, Fern ED, O'Rourke N, Vasikaran S, et al. The assessment of vertebral deformity: a method for use in population studies and clinical trials. Osteoporos Int. 1993; 3: 138-147.

241. Li Q, Amano K, Link TM, MA CB. Advanced Imaging in Osteoarthritis. Sports Health. 2016; 8: 418-428. DOI: 10.1177/1941738116663922.

242. Raine S, Twomey L. Posture of the head, shoulders and thoracic spine in comfortable erect standing. Aust J Physiother.1994; 40: 25-32. DOI: 10.1016/S0004-9514(14)60451-7.

243. Falla D, Jull G, Russell T, Vincenzino B, Hodges P. Effect of neck exercise on sitting posture in patients with chronic neck pain. Phys Ther. 2007; 87: 408-417. DOI: 10.2522/ptj.20060009.

244. Raine S, Twomey LT. Head and shoulder posture variations in 160 asymptomatic women and men. Arch Phys Med Rehabil. 1997; 78: 1215-1223. DOI: 10.1016/S0003-9993(97)90335-X.

245. Lau KT, Cheung KY, Chan KB, Chan MH, Lo KY, Wing Chiu T. Relationships between sagittal postures of thoracic and cervical spine, presence of neck pain, neck pain severity and disability. Man Ther. 2010; 15: 457-462. DOI: 10.1016/j.math.2010.03.009.

246. Shaghayegh Fard B, Ahmadi A, Maroufi N, Sarrafzadeh J. Evaluation of forward head posture in sitting and standing positions. Eur Spine J. 2016; 25: 3577-3582. DOI: 10.1007/s00586-015-4254-x.

247. van Niekerk S-M, Louw Q, Vaughan C, Grimmer-Somers K, Schreve K. Photographic measurement of upper-body sitting posture of high school students: a reliability and validity study. BMC Musculoskelet Disord. 2008; 9: 113-113. DOI: 10.1186/1471-2474-9-113.

248. Fischer AA. Pressure algometry over normal muscles. Standard values, validity and reproducibility of pressure threshold. Pain. 1987; 30: 115-126. DOI: 10.1016/0304-3959(87)90089-3.

249. Maitland G, Hengeveld E, Banks K. Maitland's Vertebral Manipulation. 7th edition. Oxford, UK: Butterworth Heinemann; 2005.

250. Waller R, Straker L, O'Sullivan P, Sterling M, Smith A. Reliability of pressure pain threshold testing in healthy pain free young adults. Scand J Pain. 2015; 9: 38-41. DOI: 10.1016/j.sjpain.2015.05.004.

251. Frank L, McLaughlin P, Vaughan B. The repeatability of pressure algometry in asymptomatic individuals over consecutive days. Int J Osteopat Med. 2013; 16: 143-152. DOI: 10.1016/j.ijosm.2012.10.004.

252. Keating L, Lubke C, Powell V, Young T, Souvlis T, Jull G. Mid-thoracic tenderness: a comparison of pressure pain threshold between spinal regions, in asymptomatic subjects. Man Ther. 2001; 6: 34-39. DOI: 10.1054/math.2000.0377.

253. Bisset LM, Evans K, Tuttle N. Reliability of 2 protocols for assessing pressure pain threshold in healthy young adults. J Manipulative Physiol Ther. 2015; 38: 282-287. DOI: 10.1016/j.jmpt.2015.03.001.

254. Waller R, Smith AJ, O'Sullivan PB, Slater H, Sterling M, McVeigh J, et al. Pressure and cold pain threshold reference values in a large, young adult, pain-free population. Scand J Pain. 2016; 13: 114-122. DOI: 10.1016/j.sjpain.2016.08.003.

255a. Spencer L, Fary R, McKenna L, Ho R, Briffa K. Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods. Osteoporos Int. 2019; 30(10): 2009-2018. DOI: 10.1007/s00198-019-05023-5.

255b. Spencer L, Fary R, McKenna L, Jacques A, Lalor J, Briffa K. The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women. Women's Health. 2020; 16: 1-11. DOI: 10.1177/1745506520918335.

256a. Spencer L, McKenna L, Fary R, Jacques A, Briffa K. Upper back pain in postmenopausal women and associated physical characteristics. PLoS One. 2019; 14: e0220452. DOI: 10.1371/journal.pone.0220452.

256b. Spencer L, McKenna L, Fary R, Ho R, Briffa K. Is breast size related to prevalent thoracic verterbal fracture? A cross-sectional study. J Bone Miner Res Plus. 2020; DOI: 10.1002/jbm4.10371.

257. Dunk NM, Lalonde J, Callaghan JP. Implications for the use of postural analysis as a clinical diagnostic tool: reliability of quantifying upright standing spinal postures from photographic images. J Manipulative Physiol Ther. 2005; 28: 386-392. DOI: 10.1016/j.jmpt.2005.06.006.

258. Balaguier R, Madeleine P, Vuillerme N. Is one trial sufficient to obtain excellent pressure pain threshold reliability in the low back of asymptomatic individuals? A test-retest study. PLoS One. 2016; 11: e0160866-e0160866. DOI: 10.1371/journal.pone.0160866.

259. Walton D, MacDermid J, Nielson W, Teasell R, Brown L. Reliability, standard error, and minimum detectable change of clinical pressure pain threshold testing in people with and without acute neck pain. J Orthop Sports Phys Ther. 2011; 41: 644-650. DOI: 10.2519/jospt.2011.3666.

260. Haneline MT, Cooperstein R, Young MD, Ross J. Determining spinal level using the inferior angle of the scapula as a reference landmark: a retrospective analysis of 50 radiographs. J Can Chiropr Assoc. 2008; 52: 24-29.

261. Field D. Anatomy, palpation and surface markings. 3rd edition. Oxford, UK: Butterworh-Heinemann; 2001.

262a. Weir JP. Quantifying test-retest reliability using the intraclass correlation coefficient and the SEM. J Strength Cond Res. 2005; 19: 231-240. DOI: 10.1519/15184.1.

262b. Portney L, Watkins M. Foundations of clinical research applications to practice. 3rd edition. New Jersey, USA: Pearson Prentice Hall; 2009.

263. Cohen J. A power primer. Psychol Bull. 1992; 112: 155-159..

264. Lee C-h, Lee S, Shin G. Reliability of forward head posture evaluation while sitting, standing, walking and running. Hum Mov Sci. 2017; 55: 81-86. DOI:10.1016/j.humov.2017.07.008.

265. Yip CH, Chiu TT, Poon AT. The relationship between head posture and severity and disability of patients with neck pain. Man Ther. 2008; 13: 148-154. DOI: 10.1016/j.math.2006.11.002.

266. Vandeweyer E, Hertens D. Quantification of glands and fat in breast tissue: an experimental determination. Ann Anat. 2002; 184: 181-184. DOI: 10.1016/s0940-9602(02)80016-4.

267. Coltman CE, Steele JR, McGhee DE. Can breast characteristics predict upper torso musculoskeletal pain? Clin Biomech. 2018; 53: 46-53. DOI: 10.1016/j.clinbiomech.2018.02.002.

268. Eric M, Anderla A, Stefanovic D, Drapsin M. Breast volume estimation from systematic series of CT scans using Cavalieri principle and 3D reconstruction. Int J Surgery. 2014; 912-917. DOI: 10.1016/j.ijsu.2014.07.018.

269. Alwers E, Gonzalez A, Torres F, Arbelaez J, Gaitan A, Cendales R. Correlation between clinically measured breast size and CT-measured breast volume: implications for prone breast radiotherapy. J Radiother Pract. 2016; 15: 354-358. DOI: 10.1017/S1460396916000352.

270. Isaac KV, Murphy BD, Beber B, Brown M. The reliability of anthropometric measurements used preoperatively in aesthetic breast surgery. Aesthet Surg J. 2016; 36: 431-437. DOI: 10.1093/asj/sjv210.

271. Machida Y, Nakadate M. Breast shape change associated with aging: A study using prone breast magnetic resonance imaging. Plast Reconstr Surg. 2015; 3: e413. DOI: 10.1097/GOX.0000000000000289.

272. Kottner J, Audige L, Brorson S, Donner A, Gajewski B, Hrobjartsson A, et al. Guidelines for reporting reliability and agreement studies (GRRAS) were proposed. J Clin Epidemiol. 2011; 64: 96-106. DOI: 10.1016/j.jclinepi.2010.03.002.

273. Linton SJ, Flink IK, Vlaeyen JWS. Understanding the etiology of chronic pain from a psychological perspective. Phys Ther. 2018; 98: 315-324. DOI: 10.1093/ptj/pzy027.

274. Sitthipornvorakul E, Janwantanakul P, Purepong N, Pensri, P, van der Beek A. The association between physical activity and neck and low back pain: a systematic review. Eur Spine J. 2011; 20: 677-689. DOI: 10.1007/s00586-010-1630-4.

275. Gill DL, Hammond CC, Reifsteck EJ, Jehu C, Williams R, Adams M, et al. Physical activity and quality of life. J Prev Med Public Health. 2013; 46 Suppl 1: S28-S34. DOI: 10.3961/jpmph.2013.46.S.S28.

276. Dugan SA, Everson-Rose SA, Karavolos K, Sternfeld B, Wesley D, Powell L. The impact of physical activity level on SF-36 role-physical and bodily pain indices in midlife women. J Phys Act Health. 2009; 6: 33-42.

277. Nayir T, Uskun E, Yürekli MV, Devren H, Celik A, Okyay R. Does body image affect quality of life?: A population based study. PLoS One. 2016; 11: e0163290-e0163290. DOI: 10.1371/journal.pone.0163290.

278. Daley A, MacArthur C, Stokes-Lampard H, McManus R, Wilson S, Mutire N. Exercise participation, body mass index, and health-related quality of life in women of menopausal age. Brit J Gen Pract. 2007; 57: 130.

279. MacKinnon DP, Krull JL, Lockwood CM. Equivalence of the mediation, confounding and suppression effect. Prev Sci. 2000; 1: 173-181.

280. Nemmers TM, Miller JW, Hartman MD. Variability of the forward head posture in healthy community-dwelling older women. J Geriatr Physl Ther. 2009; 32: 10-14.

281. Singla D, Veqar Z. Association between forward head, rounded shoulders, and increased thoracic kyphosis: A review of the literature. J Chiropr Med. 2017. DOI: 10.1016/j.jcm.2017.03.004.

282. Janiszewski PM, Saunders TJ, Ross R. Breast volume is an independent predictor of visceral and ectopic fat in premenopausal women. Obesity. 2010; 18: 1183-1187. DOI: 10.1038/oby.2009.336.

283. Kerrigan CL, Collins ED, Kim HM, Schnur P, Wilkins E, Cunningham B, et al. Reduction mammaplasty: defining medical necessity. Med Decis Making. 2002; 22: 208-217. DOI: 10.1177/0272989x0202200309.

284. Nicoletti G, Scevola S, Faga A. Is breast reduction a functional or a cosmetic operation? Proposal of an objective discriminating criterion. J Plast Reconstr Aesthet Surg. 2009; 62: 1644-1646. DOI: 10.1016/j.bjps.2008.06.069.

285. Cunningham BL, Gear AJ, Kerrigan CL, Collins E. Analysis of breast reduction complications derived from the BRAVO study. Plast Reconstr Surg. 2005; 115: 1597-1604.

286. Ogunleye AA, Leroux O, Morrison N, Preminger A. Complications after reduction mammaplasty: A comparison of wise pattern/inferior pedicle and vertical scar/superomedial pedicle. Ann Plast Surg. 2017; 79: 13-16. DOI: 10.1097/sap.0000000000001059.

287. Macdermid JC, Walton DM, Cote P, Santguida P, Gross A, Carlesso L. Use of outcome measures in managing neck pain: an international multidisciplinary survey. Open Orthop J. 2013; 7: 506-520. DOI: 10.2174/1874325001307010506.

288. Revicki D, Hays RD, Cella D, Sloan J. Recommended methods for determining responsiveness and minimally important differences for patient-reported outcomes. J Clin Epidemiol. 2008; 61: 102-109. DOI: 10.1016/j.jclinepi.2007.03.012.

289. Ghasemi A, Zahediasl S. Normality tests for statistical analysis: a guide for non-statisticians. Int J Endocrinol Metab. 2012; 10: 486-489. DOI: 10.5812/ijem.3505.

290. Curran-Everett D. Explorations in statistics: the assumption of normality. Adv Physiol Educ. 2017; 41: 449-453. DOI: 10.1152/advan.00064.2017.

291. Oberfeld D, Franke T. Evaluating the robustness of repeated measures analyses: The case of small sample sizes and nonnormal data. Behav Res Methods. 2013; 45: 792-812. DOI: 10.3758/s13428-012-0281-2.

292. Olejnik S, Algina J. Generalized eta and omega squared statistics: measures of effect size for some common research designs. Psychol Methods. 2003; 8: 434-447. DOI: 10.1037/1082-989x.8.4.434.

293. Keppel G. Design and analysis : a researcher's handbook. 4th edition. Upper Saddle River, N.J: Pearson Prentice Hall; 2004.

294. Field A. Discovering statistics using IBM SPSS statistics: and sex and drugs and rock 'n' roll. 4th edition. Los Angeles: Sage; 2013.

295. Little D, McDonald D. The use of percentage change in Oswestry Disability Index score as an outcome measure in lumbar spinal surgery. Spine. 1994; 19: 2139-2143.

296. Kovacs FM, Abraira V, Royuela A, Corcoll J, Alagre L, Tomas M, et al. Minimum detectable and minimal clinically important changes for pain in patients with nonspecific neck pain. BMC Musculoskelet Disord. 2008; 9: 43. DOI: 10.1186/1471-2474-9-43.

297. Wasserstein RL, Schirm AL, Lazar NA. Moving to a world beyond "p < 0.05". Am Stat. 2019; 73: 1-19. DOI: 10.1080/00031305.2019.1583913.

298. Cogliandro A, Barone M, Cassotta G, Tenna S, Cagli B, Persichetti P. Patient satisfaction and clinical outcomes following 414 breast reductions: Application of BREAST-Q. Aesthet Plast Surg 2017; 41: 245-249. DOI: 10.1007/s00266-016-0774-y.

299. Nicoletti G, Passaro I, Malovini A, Faga A, Toffola E. Objective integrated assessment of functional outcomes in reduction mammaplasty. Plast Reconstr Surg. 2013; 1: e61. DOI: 10.1097/gox.0000000000000004.

300. Hockings RL, McAuley JH, Maher CG. A systematic review of the predictive ability of the Orebro Musculoskeletal Pain Questionnaire. Spine. 2008; 33: E494-500. DOI: 10.1097/BRS.0b013e31817ba3bb.

301. Alanay A, Pekmezci M, Karaeminogullari O, Acaroglu E, Yazici M, Cil A, et al. Radiographic measurement of the sagittal plane deformity in patients with osteoporotic spinal fractures evaluation of intrinsic error. Eur Spine J. 2007; 16: 2126-2132. DOI: 10.1007/s00586-007-0474-z.

302. Heuch I, Heuch I, Hagen K, Zwart J. Body mass index as a risk factor for developing chronic low back pain: a follow-up in the Nord-Trondelag Health Study. Spine. 2013; 38: 133-139. DOI: 10.1097/BRS.0b013e3182647af2.

303. Dionne CE, Dunn KM, Croft PR. Does back pain prevalence really decrease with increasing age? A systematic review. Age Ageing. 2006; 35: 229-234. DOI: 10.1093/ageing/afj055.

304. Fejer R, Leboeuf-Yde C. Does back and neck pain become more common as you get older? A systematic literature review. Chiropr Man Ther. 2012; 20: 24. journal article. DOI: 10.1186/2045-709x-20-24.

305. Gibson SJ, Helme RD. Age-related differences in pain perception and report. Clin Geriatr Med. 2001; 17: 433-456.

306. Shephard RJ. Limits to the measurement of habitual physical activity by questionnaires. Brit J Sports Med. 2003; 37: 197-206. DOI: 10.1136/bjsm.37.3.197.

307. Webster S, Khan A, Nitz JC. A brief questionnaire is able to measure population physical activity levels accurately: A comparative validation study. J Clin Gerontol Geriatr. 2011; 2: 83-87. DOI: 10.1016/j.jcgg.2011.06.003.

308. Picavet HSJ, Hoeymans N. Health related quality of life in multiple musculoskeletal diseases: SF-36 and EQ-5D in the DMC$_3$ study. Ann Rheum Dis. 2004; 63: 723. DOI: 10.1136/ard.2003.010769.

309. Moseley GL, Butler DS. Fifteen Years of Explaining Pain: The Past, Present, and Future. J Pain. 2015; 16: 807-813. DOI: 10.1016/j.jpain.2015.05.005.

310. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. Clin Biomech. 1996; 11: 1-15.

311. Goel VK, Kong W, Han JS, Weinstein J, Gilbertson L. A combined finite element and optimization investigation of lumbar spine mechanics with and without muscles. Spine. 1993; 18: 1531-1541.

312. Itoi E, Sinaki M. Effect of back-strengthening exercise on posture in healthy women 49 to 65 years of age. Mayo Clin Proc. 1994; 69: 1054-1059.

313. Miyakoshi N, Kudo D, Hongo M, Kasukawa Y, Ishikawa Y, Shimada Y. Comparison of spinal alignment, muscular strength, and quality of life between women with postmenopausal osteoporosis and healthy volunteers. Osteoporos Int. 2017; 28: 3153-3160. DOI: 10.1007/s00198-017-4184-z.

314. Jang HJ, Kim MJ, Kim SY. Effect of thorax correction exercises on flexed posture and chest function in older women with age-related hyperkyphosis. J Phys Ther Sci. 2015; 27: 1161-1164. DOI: 10.1589/jpts.27.1161.

315. Katzman WB, Sellmeyer DE, Stewart AL, Wanek L, Hamel K. Changes in flexed posture, musculoskeletal impairments, and physical performance after group exercise in community-dwelling older women. Arch Phys Med Rehabil. 2007; 88: 192-199. DOI: 10.1016/j.apmr.2006.10.033.

316. O'Neill TW, Felsenberg D, Varlow J, Cooper C, Kanis J, Silman A. The prevalence of vertebral deformity in european men and women: the European Vertebral Osteoporosis Study. J Bone Miner Res. 1996; 11: 1010-1018. DOI: 10.1002/jbmr.5650110719.

317. Waterloo S, Ahmed LA, Center JR, Eisman J, Morseth B, Nguyen D, et al. Prevalence of vertebral fractures in women and men in the population-based Tromsø Study. BMC Musculoskelet Disord. 2012; 13: 3. DOI: 10.1186/1471-2474-13-3.

318. Kanis JA. on behalf of the World Health Organization Scientific Group. Assessment of osteoporosis at the primary health-care level: WHO Technical Report. Geneva: World Health Organisation; 2007 [cited 2019 May 05]. Available at: https://www.sheffield.ac.uk/FRAX/pdfs/WHO_Technical_Report.pdf.

319. Briggs A, Greig AM, Wark JD. The verterbal fracture cascade in osteoporosis: a review of aetiopathogenesis. Osteoporos Int. 2007; 18: 575-584.

320. Briggs A, Greig AM, Wark JD, Fazzalari N, Bennell K. A review of anatomical and mechanical factors affecting vertebral body integrity. Int J Med Sci. 2004; 1: 170-180.

321. Marini I, Bortolotti F, Bartolucci ML, Inelman E, Gatto M, Bonetti G. Aging effect on pressure pain thresholds of head and neck muscles. Aging Clin Exp Res. 2012; 24: 239-244. DOI: 10.3275/8021.

322. Grossi DB, Chaves TC, Goncalves MC, Moreira V, Canonica A, Florencio L, et al. Pressure pain threshold in the craniocervical muscles of women with episodic and chronic migraine: a controlled study. Arq Neuropsiquiatr. 2011; 69: 607-612.

323. Farasyn A, Meeusen R. The influence of non-specific low back pain on pressure pain thresholds and disability. Eur J Pain. 2005; 9: 375-381. DOI: 10.1016/j.ejpain.2004.09.005.

324. Lorbergs AL, Allaire BT, Yang L, Kiel D, Cupples L, Jarraya M, et al. A longitudinal study of trunk muscle properties and severity of thoracic kyphosis in women and men: The Framingham Study. J Gerontol Biol Sci Med Sci. 2018. DOI: 10.1093/gerona/gly056.

325. Melia M, Geissler B, Konig J, Ottersbach H, Umbreit M, Letzel S, et al. Pressure pain thresholds: Subject factors and the meaning of peak pressures. Eur J Pain. 2019; 23: 167-182. DOI: 10.1002/ejp.1298.

326. Waller R, Smith AJ, O'Sullivan PB, Slater H, Sterling M, Straker LM. Associations between musculoskeletal pain experience and pressure and cold pain sensitivity: A community-based cross-sectional study of young adults in the Raine study. Clin J Pain. 2019; 35: 56-64. DOI: 10.1097/ajp.0000000000000650.

327. Antonaci F, Sand T, Lucas GA. Pressure algometry in healthy subjects: inter-examiner variability. Scand J Rehabil Med. 1998; 30: 3-8.

328. Binderup AT, Arendt-Nielsen L, Madeleine P. Pressure pain sensitivity maps of the neck-shoulder and the low back regions in men and women. BMC Musculoskelet Disord. 2010; 11: 234. DOI: 10.1186/1471-2474-11-234.

329. Schooling M, Jones H. Clarifying questions about "risk factors": predictors versus explanation. Emerg Themes Epidemiol. 2018; 15:10. DOI: 10.1186/s12982-018-0080-z.

Appendices

Appendix 1a: Study promotion and recruitment material – poster (pilot sample)

Appendix 1b: Participant information and consent form – pilot study 1

Back Breast & Bra Study

Information Sheet & Consent Form

Curtin University

HREC Project Number:	RDHS-18-16
Project Title:	Back, breast & bra study. Pilot Study 1. Pressure pain thresholds
Principal Investigator:	Linda Spencer (PhD Candidate)
Version Number:	1
Version Date:	17/01/2015

The Project

Upper back pain is a common complaint affecting many women. Older women and women with large breasts are two groups of women that show changes in their posture which often leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

This Pilot Study

The project involves a number of measures which require testing/piloting before it can start. This pilot study involves the measurement of pain in the upper back (spine & muscles) using a handheld device (digital algometer). This instrument works by applying pressure to the skin over a point of interest and measuring how much pressure the point can withstand before pain is felt. This pilot study aims to check how reliable this method is when used by a physiotherapist investigator. The information we retrieve from this pilot study will be used to refine the procedures of the main project.

The Research Team

The project is being conducted by Linda Spencer. Linda is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project and pilot testing.

The Search for Volunteers

We are looking for healthy adult women (40yrs+) to participate in this pilot study. There will be no cost to you for taking part in this pilot study.

Taking part in this pilot study is voluntary. If you decide to take part and then change your mind, you can withdraw at any time. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues. You are under no obligation to participate further in the main project by being a participant in this pilot study.

The Role of the Volunteer

As a participant in this study you will be asked to:
1. Complete a screening questionnaire (online/paper copy) about your health to check you are eligible to participate in the study. This should take approximately 5 minutes.
2. Attend two appointments (at the physiotherapy clinic convenient to you) lasting approximately 30 minutes with the physiotherapist investigator, Linda Spencer. At these appointments several points on your upper back and torso will be tested using the digital algometer (see below).

During the appointments the following procedure will be completed:

Preparation

- You will be asked to avoid any unaccustomed activity (that may cause temporary soreness) 48 hours prior to both of the test appointments.
- Upon arrival to the clinic you will be shown to a private lockable room in the clinic where the testing will take place. The physiotherapist investigator (LS) and an experienced female clinician will be with you in the room. The door will locked to ensure privacy.
- The procedure will be explained to you verbally and you will be able to ask any questions.
- You will be asked to stand while 12 anatomical points are located and marked on your upper body and back with hypoallergenic tape and a non-permanent (make-up) marker pen. You will be asked to undress your upper body for this. An open-back gown will be provided for your comfort. Lower limb clothing can be worn.
- The testing equipment will be shown to you and how it works will be demonstrated on your hand. Once you are happy with the procedure the testing will begin:

The Testing

- Twelve points on your upper body and back will be tested in total. Each point will be tested three times. The order that they are tested in will be randomly determined.
- You will be asked to position yourself on the treatment bed (plinth) for each measurement to take place. For some points you will be asked to lay on your back and for others you will be asked to lay on your stomach with your head in the hole of the plinth. Your arms will be by your sides. You will hold an electronic switch in your hand which is connected to the equipment being used by the physiotherapist investigator.
- Once you are comfortably in position, the probe of the handheld device (digital algometer) will be placed on the first point by the researcher. Pressure will slowly be applied to the point at a steadily increasing rate.
- You will be asked to indicate by pushing an electronic button (held in your hand) if and when the point becomes painful as pressure is being applied. At this point no further pressure will be applied and reading will be recorded by the experienced clinician (in session one) or the physiotherapist investigator (in session two).
- This will be repeated two more times on the same point following a rest interval of 30-seconds each time. Once three measures have been completed the researcher will move on to the next point and repeat the same process. All testing should be completed within 30 minutes.

The Benefits

Your participation in this study will assist in the designing of the main research project. Your contribution to this process will be greatly valued and appreciated.

Your Privacy:

The session will be held at one of two locations: Curtin Interprofessional Health and Wellness Centre or Peel Physiotherapy Centre. The procedures will take place in a private and secured room within these locations with only the researcher and a female experienced clinician present. Free parking will be provided for your visit.

You will be asked to expose your upper body for the measurements to take place. You will be provided with an open-back gown and ample draping to ensure your comfort throughout the session.

Back breast & bra study _Pilot study 1. Pressure pain thresholds_PICF_Version 1, 17/01/2016   RDHS 18-16   Page 2 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA),

279

All of your personal details and data will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data will only be accessible to the research team and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this pilot study may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

The Risks
The procedures will require lay in two positions (including laying on your stomach). If you have difficulty with changing position or feel unable to maintain a position for long you must inform the physiotherapist investigator prior to attending.

The procedure which measures upper back pain will induce temporary discomfort. A small handheld device will be pressed on your back joints and muscle to assess how sensitive they are. You will be asked to indicate when pressure becomes discomfort using a handheld cut-off switch. At this point pressure will stop being applied and the device will be withdrawn from contact with your back. Ongoing pain felt following the session is unlikely. If pain is felt temporarily following the session it should be reported to the Physiotherapist Investigator.

The Contact Details
Contact Linda Spencer if you would like to discuss any aspect of the pilot study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Tel. **08 9266 3666**

If you decide to take part in this pilot study we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the pilot study. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information sheet and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS-18-16). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Pilot study 1. Pressure pain thresholds_PICF_Version 1, 17/01/2016   RDHS 18-16   Page 3 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA).

280

Information Sheet & Consent Form

Back Breast & Bra Study

Curtin University

HREC Project Number:	RDHS-18-16
Project Title:	Back, breast and bra study. Pilot Study 1. Pressure pain thresholds
Principal Investigator:	Linda Spencer PhD Candidate
Version Number:	1
Version Date:	17/01/2016

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Please return this completed form to:

Mail: Linda Spencer (PhD Candidate)
C/o Associate Professor Kathy Briffa.
School of Physiotherapy & Exercise Science
Curtin University
Kent Street
Bentley WA.

Email: Linda.spencer@postgrad.curtin.edu.au

Back breast & bra study _Pilot study 1. Pressure pain thresholds_PICF_Version 1, 17/01/2016   RDHS 18-16   Page 4 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA).

281

Appendix 1c: Participant screening questionnaire – pilot study 1

Back Breast & Bra Study

Curtin University

Screening Questionnaire
Pilot Study 1. Pressure Pain Thresholds

The information you provide on this form will be confidential and de-identified once submitted.

Personal Details

Your personal details may be required if the researcher needs to contact you throughout the study.

Name: _____   Age: _____

Address: _____   Height _____

Phone: _____   Weight: _____

Email: _____   Bra size: _____

You and your health

1. Rate your health
   - ☐ Poor
   - ☐ Average
   - ☐ Good
   - ☐ Excellent

2. Have you ever had any of the following:
   - ☐ Chronic pain condition
   - ☐ Systemic inflammatory disease (e.g. rheumatoid arthritis; ankylosing spondylitis)
   - ☐ Neurodegenerative disorder (e.g. multiple sclerosis; stroke; Parkinson's disease)
   - ☐ Thoracic spine condition
   - ☐ Osteoporosis (reduced bone density)

3. In the past 5 years have you had any of the following:
   - ☐ Cancer involving the bones
   - ☐ Surgery involving the upper body

4. Are you regularly taking any medication for pain relief?
   - ☐ Yes
   - ☐ No

5. Are you regularly taking any medication that affects your sensation?
   - ☐ Yes
   - ☐ No

Screening Questionnaire
Pilot Study 1. Pressure Pain Thresholds

You and your body

1. In the past **six months** have you experienced any upper back pain in the region shaded yellow in this picture?
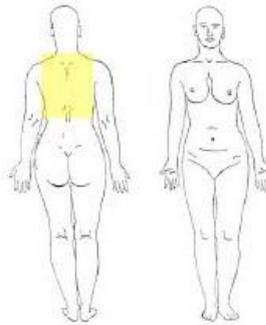
   ☐ Yes
   ☐ No

2. Are you able to lay on your stomach comfortably?
   ☐ Yes
   ☐ No

3. For the purposes of this pilot study are you willing to undress your upper body and wear an open-backed gown (lower limb clothing remain worn)?
   ☐ Yes
   ☐ No

4. Do you have any allergies?
   ☐ No
   ☐ Yes   Please specify _____

Back breast & bra study_Pilot study 2_posture assessment_flyer_version 1_ 18Jan2016 RDHS-34-16

Curtin University is a trademark of Curtin University of Technology.
CRICOS Provider Code 00301J

Back Breast & Bra Study

Curtin University

School of Physiotherapy and Exercise

Upper back posture: Photographic assessment

Female adult (40yrs +) volunteers are invited to participate in a pilot study researching upper back posture.

This pilot study looks at upper back posture and movement and how it can be reliably measured using digital photography.

The study involves taking 4 photos of your upper back in sitting, standing and with movement.

If you want to see what your posture is like, volunteer today.

For more information or to get involved visit backbreastbrastudy.net

Make tomorrow better.

Telephone +61 8 9266 3666
curtin.edu.au

Interested? Tear off a slip.

Back breast & bra study. Pilot study 2. Posture.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Appendix 1e: Participant information and consent form – pilot study 2

Back Breast & Bra Study

Curtin University

Information Sheet & Consent Form

HREC Project Number:	RDHS 34-16
Project Title:	Back, breast & bra study. Pilot Study 2. Posture assessment
Principal Investigator:	Linda Spencer (PhD Candidate)
Version Number:	1
Version Date:	18/01/2015

The Project
Upper back pain is a common complaint affecting many women. Older women and women with large breasts are two groups of women that show changes in their posture which often leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. A large study is planned that aims to explore the relationship between upper back pain and the breast. The study involves a number of measures which require testing/piloting before it can start.

This Pilot Study
This pilot study involves the measurement of posture and movement in the upper back using digital photography. Images of the spine will be taken in various positions to do this. Attached to the spine will be photo-reflective markers that can be seen and analysed on a computer to calculate postural angles and movement. This pilot study aims to check how reliable this method is when used by a physiotherapist investigator. The information we retrieve from this pilot study will be used to refine the procedures of the main project.

The Research Team
The project is being conducted by Linda Spencer. Linda is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project and pilot testing.

The Search for Volunteers
We are looking for healthy adult women (40yrs+) to participate in this pilot study. There will be no cost to you for taking part in this pilot study.

Taking part in this pilot study is voluntary. If you decide to take part and then change your mind, you can withdraw at any time. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues. You are under no obligation to participate further in the main project by being a participant in this pilot study.

The Role of the Volunteer
As a participant in this study you will be asked to:
1. Complete a screening questionnaire (online/paper copy) about your health to check that you are eligible for participation in the study. This should take approximately 5 minutes.
2. Attend one appointment (at the physiotherapy clinic convenient to you) lasting approximately 30 minutes with the physiotherapist investigator, Linda Spencer. At the appointment four photographs of your upper back and head will be taken using a digital camera.

Back breast & bra study _Pilot study 2. Posture assessment_PICF_Version 1, 18/01/2016   RDHS 34-16   Page 1 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA).

285

During the appointment the following procedure will be completed:

Preparation

- Upon arrival to the clinic you will be shown to a private secured room in the clinic where the testing will take place. The physiotherapist investigator (LS) will be with you in the room. The door will locked to ensure privacy.
- The procedure will be explained to you verbally and you will be able to ask any questions.
- You will be asked to stand while 8 anatomical points are located and marked on your upper back using photo-reflective markers. You will be asked to expose your back for this. A gown will be provided for your comfort. Lower limb clothing will remain worn.

The Testing

- Four photographs will be taken in total. Each photograph will require you to be in a different position:
  - Photo 1: Comfortable sitting
  - Photo 2: Comfortable standing
  - Photo 3: Standing with arms elevated
  - Photo 4: Standing with hands clasped above your head, reaching up and back with your arms as far as possible whilst arching your upper back.
- The order that these photos are taken will be randomly determined at the start of the session.
- You will be asked to position yourself on a stool for the seated pictures and a mark on the floor will show you where to stand for the standing pictures. All pictures will be taken from the side with your head facing forwards.
- Before each photograph the investigator will ask you to either march on the spot for 5 seconds (for standing photographs) or to move your head forward and back 5 times (for seated photographs). This is to help relax you.
- All testing/photographs should be completed within 30 minutes.

The Benefits

Your participation in this study will assist in the designing of the main research project. Your contribution to this process will be greatly valued and appreciated.

Your Privacy:

The session will be held at one of two locations: Curtin Interprofessional Health and Wellness Centre or Peel Physiotherapy Centre. The procedures will take place in a private and secured room within these locations with only the researcher present. Free parking will be provided for your visit.

You will be asked to expose your upper back for the measurements to take place. You will be provided with an open-backed gown and ample draping to ensure your comfort throughout the session. Your lower limb clothing can remain worn.

All of your personal details and data will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data and photographs will only be accessible to the research team and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

Back breast & bra study _Pilot study 2. Posture assessment_PICF_Version 1, 18/01/2016 RDHS 34-16
Curtin University is a trademark of Curtin University of Technology.   Security Classification:

Page 2 of 4
CRICOS Provider Code 00301J (WA).

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this pilot study may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

The Risks

The procedures will require you to stand and arch your upper back. If you have think you may have difficulty with this movement or think that you become unsteady doing it, you must inform the physiotherapist investigator prior to attending.

The movement being tested is not expected to be painful. If you feel pain at any point during or after the session it should be reported to the Physiotherapist Investigator.

The Contact Details

Contact Linda Spencer if you would like to discuss any aspect of the pilot study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Tel. **08 9266 3666**

If you decide to take part in this pilot study we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the pilot study. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information sheet and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS 34-16). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Pilot study 2. Posture assessment_PICF_ Version 1, 18/01/2016 RDHS 34-16
Curtin University is a trademark of Curtin University of Technology.   Security Classification:

Page 3 of 4
CRICOS Provider Code 00301J (WA),

287

Back Breast & Bra
Study

Curtin University

HREC Project Number:	RDHS 34-16
Project Title:	Back, breast and bra study. Pilot Study 2. Posture assessment
Principal Investigator:	Linda Spencer PhD Candidate
Version Number:	1
Version Date:	18/01/2016

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Back breast & bra study _Pilot study 2. Posture assessment_PICF_Version 1, 18/01/2016   RDHS 34-16
Curtin University is a trademark of Curtin University of Technology.   Security Classification: Page 4 of 4
CRICOS Provider Code 00301J (WA).

Appendix 1f: Participant screening questionnaire – pilot study 2

Back Breast & Bra Study

Curtin University

Screening Questionnaire
Pilot Study 2. Posture Assessment

The information you provide on this form will be confidential and de-identified once submitted.

Personal Details
Your personal details may be required if the researcher needs to contact you throughout the study.

Name: _____   Age: _____

Address: _____   Height: _____

Phone: _____   Weight: _____

Email: _____   Bra size: _____

You and your health

1. In the past 5 years have you had any surgery involving the upper torso?
   - ☐ Yes
   - ☐ No

You and your body

1. In the past **six months** have you experienced any upper back pain in the region shaded yellow in this picture?
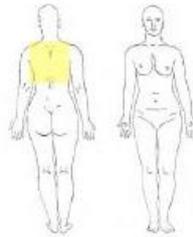
   - ☐ Yes
   - ☐ No

2. For the purposes of this pilot study are you willing to expose your upper back (wear an open-backed garment)?
   - ☐ Yes
   - ☐ No

3. Do you have any allergies?
   - ☐ No
   - ☐ Yes   Please specify _____

Back, breast & bra study_pilot study 2_POSTURE_Screening Questionnaire_version 1_20160118 RDHS-34-16   Page 1 of 1

Appendix 1g: Study promotion and recruitment material – poster (pilot sample)

Back Breast & Bra Study

Curtin University

School of Physiotherapy and Exercise Science

Breast Size & Bra Fit: Anatomical assessment & bra strap pressure measurement

Female adult (40yrs+) volunteers are invited to participate in a pilot study researching breast volume & bra strap pressure measurement

This pilot study looks at breast volume and how it can be reliably measured using anatomical dimensions. It also looks at your bra fit and measures how much pressure is under your shoulder straps.

The study involves taking measurements of your breasts using tape measure and using pressure sensors on your bra to quantify tension pressure.

If you want to find out your breast size and whether your bra maybe too tight go to:

www.backbreastbrastudy.net

**Make tomorrow better.**

Telephone +61 8 9266 3666
curtin.edu.au

Interested? Tear off a slip.

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy. net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3. Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study. Pilot study 3.Breast.
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Appendix 1h: Participant information sheet and consent form – pilot study 3
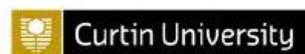
Back Breast & Bra Study

Curtin University

Information Sheet & Consent Form

HREC Project Number:	RDHS 35-16
Project Title:	Back, breast & bra study. Pilot Study 3. Breast assessment
Principal Investigator:	Linda Spencer (PhD Candidate)
Version Number:	1
Version Date:	25/01/2016

The Project

Upper back pain is a common complaint affecting many women. Older women and women with large breasts are two groups of women that show changes in their posture which often leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size or bra fit are more or less important than these other factors is unknown. A large study is planned that aims to explore the relationship between upper back pain and the breast. The study involves a number of measures which require testing/piloting before it can start.

This Pilot Study

This pilot study involves the measurement of breast size (volume) using a simple anatomical measurement technique, and bra strap pressure using electronic pressure sensor equipment. For volume measures, you will be asked to remove your bra and a tape measure will be used to acquire nipple-to-border distances of your breasts. These dimensions are then used in a mathematical formula to calculate breast volume. For strap pressure measures, a small pressure sensor will be fitted to the strap of your bra to measure tension in the strap. This pilot study aims to check how reliable these methods are when used by a physiotherapist investigator. The information we retrieve from this pilot study will be used to refine the procedures of the main project.

The Research Team

The project is being conducted by Linda Spencer. Linda is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project and pilot testing.

The Search for Volunteers

We are looking for healthy adult women (40yrs+) who have never had any breast surgery and regularly wear a bra. There will be no cost to you for taking part in this pilot study.

Taking part in this pilot study is voluntary. If you decide to take part and then change your mind, you can withdraw at any time. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues. You are under no obligation to participate further in the main project by being a participant in this pilot study.

The Role of the Volunteer

As a participant in this study you will be asked to:
1. Complete a screening questionnaire (online/paper copy) about your health to check that you are eligible for participation in the study. This should take approximately 5 minutes.

Back breast & bra study_Pilot study 3. Breast assessment_PICF_Version 1, 25/01/2016   RDHS 35-16   Page 1 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA).

291

2. Attend one appointment (at the physiotherapy clinic convenient to you) lasting approximately 45 minutes with the physiotherapist investigator, Linda Spencer. At the appointment measures will be taken of each of your breasts in two different positions. This will be repeated three times/occasions.

During each appointment the following procedure will be completed:

Preparation

- Upon arrival to the clinic you will be shown to a private secured room in the clinic where the testing will take place. The physiotherapist investigator (LS) will be with you in the room. The door will locked to ensure privacy.
- The procedure will be explained to you verbally and you will be able to ask any questions.
- You will be asked to remove your upper body clothing and bra. You will leave your lower body clothing on. An open-back gown will be provided but will need to be removed for the measures to take place.
- You will be asked to stand and remove the gown while three anatomical points are located and marked on your chest/breast using a hypoallergenic tape and non-permanent (make-up) pen.

The Testing

- Breast volume measures will be completed first.
- Four measurements will be taken on each breast. The measures will be taken by the physiotherapist investigator (LS) using a cloth tape measure. These measurements will be completed with you in two different positions:
    - Sitting unsupported on a treatment plinth with feet flat on floor and hands clasped behind you.
    - Laying on your back with your trunk turned to one side to expose the uppermost breast with the nipple positioned centrally in the breast tissue for measurement. Your hand on the upper side will be placed behind your head.
- The order that these measurements are taken and your position (sitting or standing) will be randomly determined at the start of the session.
- All testing/measurement should be completed within 45 minutes.
- The same procedure will occur three times (occasions) at the appointment. You will have a seated rest for 10 mins between each occasion. A gown will be provided for you to wear during this rest period.
- For bra strap pressure measurements you will be asked to put your bra on before the pressure sensor equipment is fitted to your shoulder strap. Measures will be taken in standing and sitting.
- You will be asked to stand whilst three data collection trials are completed, each lasting 10-seconds. You will need to stand comfortably still for each trial.
- You will then be asked to sit unsupported and comfortably still on the treatment plinth whilst the same procedure is repeated another three times.
- The pressure data will be captured electronically by the equipment and displayed on a computer screen.

The Benefits

Your participation in this study will assist in the designing of the main research project. Your contribution to this process will be greatly valued and appreciated.

Information Sheet & Consent Form

Your Privacy:

The session will be held at one of two locations: Curtin Interprofessional Health and Wellness Centre or Peel Physiotherapy Centre. The procedures will take place in a private and secured room within these locations with only the researcher present. Free parking will be provided for your visit.

You will be asked to expose your upper body for the measurements to take place. You will be provided with a gown and ample draping to ensure your comfort throughout the session.

All of your personal details and data will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data will only be accessible to the research team and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this pilot study may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

The Risks

The measurements will require the physiotherapist investigator (LS) to touch your breast and nipple as the tape measure is positioned appropriately. You may be asked to assist with positioning your breasts as required for the measurements to be taken. If you feel uncomfortable at any time during the session you must inform the physiotherapist investigator.

The Contact Details

Contact Linda Spencer if you would like to discuss any aspect of the pilot study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Tel. **08 9266 3666**

If you decide to take part in this pilot study we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the pilot study. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information sheet and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS 35-16). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Pilot study 3. Breast assessment_PICF_Version 1, 25/01/2016   RDHS 35-16   Page 3 of 4
Curtin University is a trademark of Curtin University of Technology.   Security Classification: CRICOS Provider Code 00301J (WA).

293

![Back Breast & Bra Study logo] ![Curtin University logo]

Information Sheet & Consent Form

HREC Project Number:	RDHS 35-16
Project Title:	Back, breast and bra study. Pilot Study 3. Breast assessment
Principal Investigator:	Linda Spencer PhD Candidate
Version Number:	1
Version Date:	25/01/2016

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Bra strap pressure measurement was considered and developed as a measure but despite 40 hours of development and pilot trial, data collection in 19 participants, was inconsistent and unsuitable for use. Bra strap pressure measurement data has not been reported as the method trialed was not reliable or valid.

Appendix 1i: Participant screening questionnaire – pilot study 3

Back Breast & Bra Study

Curtin University

Screening Questionnaire
Pilot Study 3. Breast Assessment

The information you provide on this form will be confidential and de-identified once submitted.

Personal Details

Your personal details may be required if the researcher needs to contact you throughout the study.

Name: _____   Age: _____
Address: _____   Height _____
Phone: _____   Weight: _____
Email: _____   Bra size: _____

You and your Breasts

1. Have you ever had any surgery involving the breast?
   ☐ Yes
   ☐ No

2. Do you wear a bra on a regular basis?
   ☐ Yes
   ☐ No

You and your body

1. For the purposes of this pilot study are you willing to undress your upper body, including your bra?
   ☐ Yes
   ☐ No

2. Do you have any allergies?
   ☐ No
   ☐ Yes   Please specify _____

Appendix 2a: Participant information sheet and consent form - community-based sample

Back Breast & Bra
Study

Information Sheet & Consent Form
Study 1

 Curtin University

HREC Project Number:	RDHS-267-15
Project Title:	Back, breast & bra study. Study 1.
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	11/10/2015

The Project

Upper back pain is a common complaint affecting many women. Older women often show changes in their posture which leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

The Research Team

The project is being conducted by Linda Spencer who is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project.

The Search for Volunteers

We are looking for healthy mature women to participate in this study. You have been asked to take part because you are of least 40 years of age. You will be asked to complete a series of questionnaires for this study. There will be no cost to you for taking part in this research.

Taking part in a research project is voluntary. If you decide to take part and then change your mind, you can withdraw from the project. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues.

The Role of the Volunteer

As a participant in this study you will be asked to:

- Complete a number of questionnaires (paper copies or online) about your health, back pain, breast symptoms; bras and medications. This is likely to take approximately 30 mins.
- Select if you are interested in continuing your participation in a follow-up study where physical measures of the upper back, posture and breasts would be completed.

Back breast & bra study _Study1_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 1 of 3

Back Breast & Bra Study

Curtin University

Your Privacy:

All of your personal details and questionnaire data will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data will only be accessible to the principal investigator and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this research may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

The Risks

There are no identifiable risks from participating in this study.

The Contact Details

Contact Linda Spencer if you would like to discuss any aspect of the study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Telephone: **9266 4644**

If you decide to take part in this research we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the research project. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS-267-15). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Study1_ PICF_ Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 2 of 3

297

Information Sheet & Consent Form
Study 1

HREC Project Number:	RDHS-267-15
Project Title:	Back breast and bra study. Study 1.
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	11/10/2015

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Please return this completed form to:

Mail: Linda Spencer (PhD Candidate)
                   c/o Associate Professor Kathy Briffa.
                   School of Physiotherapy & Exercise Science
                   Curtin University
                   Kent Street
                   Bentley WA.

Email: Linda.spencer@postgrad.curtin.edu.au

Back breast & bra study _Study1_ PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 3 of 3

298

Appendix 2b: Participant information sheet and consent form – postmenopausal subset

Back Breast & Bra
Study

Curtin University

Information Sheet & Consent Form
Study 2

HREC Project Number:	RDHS-267-15
Project Title:	Back, breast & bra study: study 2
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	04/10/2015

The Project

Upper back pain is a common complaint affecting many women. Older women often show changes in their posture which often leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

The Research Team

The project is being conducted by Linda Spencer who is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project.

The Search for Volunteers

We are looking for healthy mature women to participate in this study. You have been asked to take part because you are of least 40 years of age and have participated in the questionnaire study prior to this. There will be no cost to you for taking part in this research.

Taking part in a research project is voluntary. If you decide to take part and then change your mind, you can withdraw from the project. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University, staff or colleagues.

The Role of the Volunteer

Having completed the questionnaires in the previous study you were randomly selected and are now invited to participate in the next part of the study. This involves having a range of physical measures taken. As a participant in this study you will be asked to:

1. Attend Curtin Interprofessional Health & Wellness Centre at Curtin University to have a bone density scan and other physical measures of your back movement, back strength, upper back pain, breast size, posture and bra (see below). This is likely to take 1 hour.
2. Attend Perth Radiological Clinic (see http://perthradclinic.com.au/locations) to have an x-ray taken of your back. This is likely to take less than 30mins.

Back breast & bra study _Study 2_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 1 of 5

The Details:

You will be asked to make your own travel arrangements to attend appointments. You will be provided with free parking at all appointments.

- **The Curtin Interprofessional Health and Wellness Centre appointment:**

Before your scheduled session at Curtin Interprofessional Health and Wellness Centre you will be asked to avoid any unaccustomed activity in the preceding 48 hours that may induce temporary muscle or joint soreness. You will be asked to bring details of all current medications and asked to attend in loose fitting attire, wearing the bra you find most comfortable.

You will be asked to attend Curtin Interprofessional Health & Wellness Clinic at a time that is convenient to you. An appointment time will be prearranged with you. Upon arrival you will have all the procedures explained to you. The tests will take place in a single room within the clinic that is locked when all tests are taking place. Only you and the female researcher will be in the room. The following tests will be completed:

Bone density scan: You will be asked to lay on your back for around 15mins for the bone density scan to be completed. You will be provided with a gown for this procedure and asked to remove any metal from your clothing/body. The scan will be completed by Linda Spencer or research supervisor.

Back movement test: You will be asked to stand with your shirt removed (bra on) for this measure. Adhesive markers will be placed on your upper spine. A photograph will be taken at the start. You will then be asked to arch your back whilst a second photograph is taken. The amount of movement you have will be measured from the photographs.

Posture assessment: You will be asked to sit with you shirt removed (bra on) for this measure. Adhesive markers will be placed on your spine and shoulder. Sitting comfortably a photograph will be taken from the side. The photograph will be used to measure your posture.

Breast measures: Several measures of your breast will be made using a tape measure. You will be asked to remove your bra for these measures.

Bra size measures: You will be asked to stand for this measure with your bra removed. A tape measure will be used to measure around your chest at points over and under your bust to determine you bra size.

Bra strap pressure: You will be asked to stand with your bra on for this measure. Small sensors will be placed under the straps of your bra at various points to measure the pressure under the strap. The sensors will be connected to a computer via wires to get this information electronically.

Back strength measures: You will be asked to lay on your stomach over a wedge cushion on the treatment bed with your clothes on for this measure. You will be asked to lift your chest and head up off the cushion and hold for as long as you can. The amount of time that you can hold this position will be recorded.

Back breast & bra study _Study 2_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 2 of 5

300

<u>Back pain measures:</u> You will be asked to sit and/or lay on your stomach. A handheld device will be placed at various points on your back (spine) and upper body (muscles) by the principal Investigator. You will be asked to indicate if and when the points become painful as pressure is applied to them using the device.

- **The X-ray appointment:**

To have your back x-ray taken you will be provided with a referral request slip to take with you. You will select the Perth Radiological Clinic location and a time that is most convenient to you. There will be no cost to you for this x-ray.

The Benefits

As a participant in this study you will incur the following benefits:
1. An interpreted back x-ray with details of any fractures or other pathology/condition.
2. A printed copy of your bone mineral density results that you can take to your GP to discuss.
3. Information on how to correctly fit your bra.

Your Privacy:

The session held at Curtin Interprofessional Health and Wellness Centre will involve a number of procedures where you will be asked to undress to expose your back or breasts to permit measures to be taken. You will be provided with a gown and ample draping to ensure your comfort throughout the session. The procedures will take place in a private and secured room with only the Linda Spencer or research supervisor present.

Photographic images will be taken as part of some of the procedures. These images will exclude facial features and any identifying marks (birth marks or tattoos) will be pixelated. The images will be coded to carefully ensure anonymity.

All of your personal details, data and images will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data will only be accessible to the research team and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this research may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

Back breast & bra study _Study 2_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 3 of 5

The Risks

The procedures will require you to sit, stand and lay in a variety of positions (including laying on your stomach). If you have difficulty with changing position or feel unable to maintain a position for long you must inform the research team prior to attending.

The procedure which measures upper back pain will induce temporary discomfort. A small handheld device will be pressed on your back joints and muscles to assess how sensitive they are. You will be asked to indicate when pressure becomes discomfort. At this point the device will be withdrawn from contact with your back. Any ongoing pain following the session should be reported to the research team.

Two procedures involved in this study will expose you to very small doses of radiation (x-ray and bone mineral density scan). The total amount of radiation that you will receive has been verified by the Curtin Radiation Safety Officer. The tests involve the use of a low dose x-rays about equal to one thousandth of the background radiation you would receive in one year living in Perth. The total background radiation in Western Australia is about 2000 µSv per year. The radiation dose from cosmic rays from flying in a jet from Perth to London is approximately 100 µSv.

During this research we may find a result that has implications for your health. You will be notified of this and advised to contact your GP at your earliest convenience.

The Contact Details

Contact Linda Spencer if you would like to discuss any aspect of the study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Telephone: **9266 4644**

If you decide to take part in this research we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the research project. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS-267-15). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Study 2_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 4 of 5

HREC Project Number:	RDHS-267-15
Project Title:	Back breast and bra study. Study 2.
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	04/10/2015

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I consent to the collection & secure storage of images of myself as part of my involvement in this project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Please return this completed form to:
Mail: Linda Spencer (PhD Candidate)
                                       c/o Associate Professor Kathy Briffa.
                                       School of Physiotherapy & Exercise Science
                                       Curtin University
                                       Kent Street
                                       Bentley WA.
Email: Linda.spencer@postgrad.curtin.edu.au

Back breast & bra study _Study 2_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 5 of 5

303

Appendix 2c: Participant information sheet and consent form – surgical sample

Back Breast & Bra Study

Curtin University

Information Sheet & Consent Form
Study 3

HREC Project Number:	RDHS-267-15
Project Title:	Back, breast & bra study. Study 3.
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	04/10/2015

The Project

Upper back pain is a common complaint affecting many women. Women with large breasts often show changes in their posture which often leads them to seek treatment for upper back pain. Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

The Research Team

The project is being conducted by Linda Spencer who is a Musculoskeletal Physiotherapist completing a Doctor of Philosophy at Curtin University. Associate Professor Kathy Briffa, Dr Robyn Fary and Dr Leanda McKenna offer substantial experience in research and are supervising Linda with the project.

The Search for Volunteers

We are looking for healthy women to participate in this study. You have been asked to take part because you are awaiting breast reduction surgery. Initially you will be asked to complete a series of questionnaires and then invited to participate further where physical measures of your back pain, posture, breasts and bra will be taken. There will be no cost to you for taking part in this research.

Taking part in a research project is voluntary. If you decide to take part and then change your mind, you can withdraw from the project. If you chose not to take part or start and then stop the study, it will not affect your relationship with the University or Breast Clinic; their staff or colleagues.

The Role of the Volunteer

Before your surgery and as a participant in this study you will be asked to:

Initially:
1. Complete a number of questionnaires (paper copies or online) about your health, back pain, breast symptoms; bras and medications. This is likely to take approximately 30 mins.

Back breast & bra study _Study 3_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 1 of 5

304

Then:

Having completed the questionnaire pack you will be invited to participate in the study further. This will include two visits (one before and one after your surgery) to Curtin Interprofessional Health & Wellness Centre at Curtin University. Here you will have a bone density scan and other physical measures of your back movement, back strength, upper back pain, breast size and posture (see below). This is likely to take 1 hour.

The Details:

You will be asked to make your own travel arrangements to attend appointments. You will be provided with free parking at all appointments.

- **The Curtin Interprofessional Health and Wellness Centre appointment:**

Before your scheduled session at Curtin Interprofessional Health and Wellness Centre you will be asked to avoid any unaccustomed activity in the preceding 48 hours that may induce temporary muscle or joint soreness. You will be asked to bring details of all current medications and asked to attend in loose fitting attire, wearing the bra you find most comfortable.

You will be asked to attend Curtin Interprofessional Health & Wellness Clinic at a time that is convenient to you. An appointment time will be prearranged with you. Upon arrival you will have all the procedures explained to you. The tests will take place in a single room within the clinic that is locked when all tests are taking place. Only you and a member of the research team will be in the room. The following tests will be completed:

Bone density scan: You will be asked to lay on your back for around 15mins for the bone density scan to be completed. You will be provided with a gown for this procedure and asked to remove any metal from your clothing/body. The scan will be completed by Linda Spencer or research supervisor.

Back movement test: You will be asked to stand with your shirt removed (bra on) for this measure. Adhesive markers will be placed on your upper spine. A photograph will be taken at the start. You will then be asked to arch your back whilst a second photograph is taken. The amount of movement you have will be measured from the photographs.

Posture assessment: You will be asked to sit with you shirt removed (bra on) for this measure. Adhesive markers will be placed on your spine and shoulder. Sitting comfortably a photograph will be taken from the side. The photograph will be used to measure your posture.

Breast measures: Several measures of your breast will be made using a tape measure. You will be asked to remove your bra for these measures.

Bra size measures: You will be asked to stand with your bra removed for this measure. A tape measure will be used to measure around your chest at points over and under your bust to determine you bra size.

Bra strap pressure: You will be asked to stand with your bra on for this measure. Small sensors will be placed under the straps of your bra at various points to measure the pressure under the strap. The sensors will be connected to a computer via wires to retrieve this information electronically.

Back breast & bra study _Study 3_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 2 of 5

Back strength measures: You will lay on your stomach over a wedge cushion on a treatment bed with your clothes on for this measure. You will be asked to lift your chest off of the cushion and hold for as long as you can. The amount of time that you can hold this position will be recorded.

Back pain measures: You will be asked to sit and/or lay on your stomach. A handheld device will be placed at various points on your back (spine) and upper body (muscles). You will be asked to indicate if and when the points become painful as pressure is applied to them using the device.

As a participant undergoing breast reduction surgery we are interested to see if any of these measures change as a result. Therefore you will be asked to attend at any stage prior to your surgery and then again at least three months following your surgery when it is comfortable for you to move and lay on your stomach. The same measures will be taken at both sessions. You will be asked to provide details of your surgery (e.g. how much breast tissue was removed and the type of incision made on your breast) and will be asked to complete a surgery satisfaction questionnaire at the second session.

The Benefits

As a participant in this study you will incur the following benefits:
1. A printed copy of your bone mineral density results that you can take to your GP to discuss.
2. Information on how to correctly fit your bra.

Your Privacy:

The session held at Curtin Interprofessional Health and Wellness Centre will involve a number of procedures where you will be asked to undress to expose your back or breasts to permit measures to be taken. You will be provided with a gown and ample draping to ensure your comfort throughout the session. The procedures will take place in a private and secured room with only a member of the research team present.

Photographic images will be taken as part of some of the procedures. These images will exclude facial features and any identifying marks (birth marks or tattoos) will be pixelated. The images will be coded to carefully ensure anonymity.

All of your personal details, data and images will be de-identified, coded, protected and stored securely. The study has to adhere to strict guidelines which will ensure confidentiality. The data will only be accessible to the research team and used for research purposes only. The Curtin Ethics Office may access the data for audit purposes.

The information we collect in this study will be kept under secure conditions at Curtin University for 7 years after the research has ended and then it will be destroyed.

The results of this research may be presented at conferences or published in professional journals. You will not be identified in any results that are published or presented.

Back breast & bra study _Study 3_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 3 of 5

The Risks

The procedures will require you to sit, stand and lay in a variety of positions (including laying on your stomach). If you have difficulty with changing position or feel unable to maintain a position for long you must inform the research team prior to attending.

The procedure which measures upper back pain will induce temporary discomfort. A small handheld device will be pressed on your back joints and muscles to assess how sensitive they are. You will be asked to indicate when pressure becomes discomfort. At this point the device will be withdrawn from contact with your back. Any ongoing pain following the session should be reported to the research team.

One procedure involved in this study will expose you to a very small dose of radiation (bone mineral density scan). The total amount of radiation that you will receive has been verified by the Curtin Radiation Safety Officer. The test involves the use of a low dose x-rays about equal to one thousandth of the background radiation you would receive in one year living in Perth. The total background radiation in Western Australia is about 2000 µSv per year. The radiation dose from cosmic rays from flying in a jet from Perth to London is approximately 100 µSv.

During this research we may find a result that has implications for your health. You will be notified of this and advised to contact your GP at your earliest convenience.

The Contact Details

Contact Linda Spencer if you would like to discuss any aspect of the study or would like to volunteer to participate. Email: **Linda.spencer@postgrad.curtin.edu.au** or Telephone: **9266 4644**

If you decide to take part in this research we will ask you to sign the consent form. Signing the consent indicates that you have understood the information provided in this document and agree to be in the research project. Please take your time and ask any questions you have before you decide what to do. You will be given a copy of this information and the unsigned consent form to keep.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHS-267-15). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Back breast & bra study _Study 3_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 4 of 5

Information Sheet & Consent Form
Study 3

HREC Project Number:	RDHS-267-15
Project Title:	Back breast and bra study. Study 3
Principal Investigator:	Associate Professor Kathy Briffa
Version Number:	1
Version Date:	04/10/2015

- I have read, {or had read to me in my first language – delete if not appropriate}, the information statement version listed above and I understand its contents.
- I believe I understand the purpose, extent and possible risks of my involvement in this project.
- I voluntarily consent to take part in this research project.
- I consent to the collection and secure storage of images of myself as part of my involvement in this project.
- I have had an opportunity to ask questions and I am satisfied with the answers I have received.
- I understand that this project has been approved by Curtin University Human Research Ethics Committee and will be carried out in line with the National Statement on Ethical Conduct in Human Research (2007) – updated March 2014.
- I understand I will receive an unsigned copy of this Information Statement and Consent Form.

Participant Name	
Participant Signature	
Date	

Declaration by researcher: I have supplied an Information Letter and Consent Form to the participant who has signed above, and believe that they understand the purpose, extent and possible risks of their involvement in this project.

Researcher Name	
Researcher Signature	
Date	

Note: All parties signing the Consent Form must date their own signature.

Please return this completed form to:
Mail: Linda Spencer (PhD Candidate)
                C/o Associate Professor Kathy Briffa.
                School of Physiotherapy & Exercise Science
                Curtin University
                Kent Street
                Bentley WA.
Email: Linda.spencer@postgrad.curtin.edu.au

Back breast & bra study _Study 3_PICF_Version 1, 04/10/2015
Curtin University is a trademark of Curtin University of Technology.

Page 5 of 5

308

Appendix 3a: Study promotion and recruitment material – website

Appendix 3b: Study promotion and recruitment material – radio transcripts

Radio Transcript: community-based sample

Have you ever wondered whether the bra you wear, or the size of your breasts might be affecting your posture or causing pain in your upper back?

Researchers at Curtin University are seeking women who are at least 40 years of age to participate in a large study looking at the relationship between spinal posture, breast size, bra fit and back pain.

The Back, Breast and Bra study needs women with and without back pain; with breasts ranging from small through to very large. This study gives women the opportunity to have a back X-ray and bone density scan free of charge as we look at the physical characteristics of women, through a series of measures taken of your back, breasts, posture and bra fit, and their relationship to back pain. For more details visit wwwbackbreastbrastudy.net or call 9266 3666.

RDHS-267-15 version 1_26/10/2015

Radio Transcript: surgical sample

Are you a woman who is having breast reduction surgery?

Researchers at Curtin University are seeking women who are awaiting breast reduction surgery to participate in a large study looking at the relationship between spinal posture, breast size, bra fit and back pain.

The Back, Breast and Bra study needs women undergoing breast reduction surgery in the next 12 months. This study gives women the opportunity to have a back X-ray and bone density scan free of charge as we look at the physical characteristics of women before and after surgery. For more details visit wwwbackbreastbrastudy.net or call 9266 3666.

RDHS-267-15 version 2_16/11/2016

Appendix 3c: Study promotion and recruitment material – newspaper advert (community- based sample)

Back Breast & Bra Study

Curtin University

Are you female & over 40yrs old?

Do you wear a bra most days?

Contact: Linda Spencer
Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666
www.backbreastbrastudy.net
RDHS-267-15

Female Volunteers (40yrs+) are needed to participate in a large study looking at the relationship between spinal posture, breast size, bra fit and back pain. We need women with and without back pain; with breasts ranging from small through to very large. This study gives women the opportunity to have a back x-ray and bone density scan free of charge as we look at the physical characteristics of women and their relationship to back pain.

Back breast & bra study_flyer_version 1   RDHS-267-15   12Oct2015

Back Breast & Bra
Study

Curtin University

School of Physiotherapy and Exercise Science

Upper back pain

    Breast Size and Bra fit

Female volunteers are invited to participate in a study researching upper back pain. Does breast size and bra fit affect upper back pain? Three studies, one question.

Study 1: Mature women (40yrs +) to complete a series of online/paper questionnaires on their health; back pain; bra wearing habits; physical activity and menopause symptoms (if applicable).

Study 2: Mature women (40yrs +)* to have physical measures taken of their posture; back pain; breast size; bra fit; back strength; bone density and back mobility.

Study 3: Women (any age) awaiting breast reduction surgery to complete questionnaires and physical measures before and after surgery.

* Participants in study 2 must first complete study 1.

Make tomorrow better.

Telephone +61 8 9266 3666
curtin.edu.au

Interested? Tear off a slip.

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Back breast & bra study
www.backbreastbrastudy.net
Email. Linda.spencer@postgrad.curtin.edu.au
Tel. 9266 3666

Appendix 3e: Study promotion and recruitment material – leaflet (community-based sample)

Panel 1 (brochure outer – left)

Curtin University

School of Physiotherapy and Exercise Science

www.curtin.edu.au

www.backbreastbrastudy.net

The Research Team

Linda Spencer
Musculoskeletal Physiotherapist
PhD Candidate

Assoc. Prof. Kathy Briffa
Research Supervisor

Dr Robyn Fary
Research Co-supervisor

Dr Leanda McKenna
Research Co-supervisor

Panel 2 (brochure outer – centre)

Back breast & bra study _Leaflet_Studies 1& 2_Version 1
19/10/2015

Human Ethics approval number: RDHS-267-15

Curtin University

School of Physiotherapy and Exercise Science
Curtin University is a trademark of Curtin University of Technology.

Panel 3 (brochure outer – right)

Back Breast & Bra
Study

Female volunteers are invited to participate in a study researching upper back pain.

Does breast size and bra fit affect
upper back pain?

Curtin University

Panel 4 (brochure inner – left)

Back Breast & Bra
Study

Female volunteers are invited to participate in a study researching upper back pain. Does breast size and bra fit affect upper back pain?

The Study

Upper back pain is a common complaint affecting many women. Older women often show changes in their posture that can lead them to seek treatment for upper back pain.

Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

Panel 5 (brochure inner – centre)

Volunteers Needed

Study 1: Mature women (40yrs +) to complete a series of online/paper questionnaires on their health; back pain; bra wearing habits; physical activity and menopause symptoms (if applicable).
Study 2: Mature women (40yrs +) to have physical measures taken of their posture; back pain; breast size; bra fit; back strength; bone density and back mobility.

Volunteer Role

1. **Studies 1 & 2:** Complete the online/paper questionnaires
2. **Study 2:** Attend Curtin l Health & Wellness Centre at Curtin University to have a bone density scan and other physical measures of your back movement, back strength, upper back pain, breast size, posture and bra (see below). This is likely to take 1 hour.
3. **Study 2:** Attend Perth Radiological Clinic (see http://perthradclinic.com.au/locations) to have an x-ray taken of your back. This is likely to take less than 30mins.

Costs

Taking part in this research is voluntary. There are no costs involved in taking part and you can withdraw at any time.
Free parking will be available for all appointments.

Panel 6 (brochure inner – right)

The Benefits

As a participant in these two studies you will receive the following benefits:
- An interpreted back x-ray with details of any fractures or other pathology/condition.
- A printed copy of your bone mineral density results that you can take to your GP to discuss.
- Information on how to correctly fit your bra.

How to get involved

Interested in participating in study one or two or both? More information on the study and recruitment forms are available by contacting the principal investigator using the details below.

Contact Us

Linda Spencer
School of Physiotherapy & Exercise Science.
Curtin University
Bentley WA
08 9266 3666

Linda.spencer@postgrad.curtin.edu.au
www.backbreastbrastudy.net

Find us on: facebook. yammer Linked in

Appendix 3g: Study promotion and recruitment material – leaflet (surgical sample)

Curtin University

School of Physiotherapy and Exercise Science

www.curtin.edu.au

www.backbreastbrastudy.net

The Research Team

Linda Spencer
Musculoskeletal Physiotherapist
PhD Candidate

Assoc. Prof. Kathy Briffa
Research Supervisor

Dr Robyn Fary
Research Co-supervisor

Dr Leanda McKenna
Research Co-supervisor

Curtin University

School of Physiotherapy and Exercise Science
Curtin University is a trademark of Curtin University of Technology.

Back Breast & Bra

Study

Female volunteers are invited to participate in a study researching upper back pain.

Does breast size and bra fit affect
upper back pain?

Curtin University

Back Breast & Bra

Study

Female volunteers are invited to participate in a study researching upper back pain. Does breast size and bra fit affect upper back pain?

The Study

Upper back pain is a common complaint affecting many women. Women with large breasts often show changes in their posture that can lead them to seek treatment for upper back pain.

Breast size, is one factor among many that may affect posture and contribute to the pain felt in the upper back. In addition to breast size there are a number of other physical and psychological factors that may contribute to pain. Whether a woman's breast size is more or less important than these other factors is unknown. This study aims to explore the relationship between upper back pain and the breast.

Volunteers Needed

Women of any age undergoing breast reduction surgery are needed pre and post-surgery to:
- Complete a series of online/paper questionnaires on their health; back pain; bra wearing habits; physical activity and menopause symptoms (if applicable).
- Have physical measures taken of their posture; back pain; breast size; bra fit; back strength; bone density and back mobility.

Volunteer Role

1. **Pre-surgery:** Complete the online/paper questionnaires
2. **Pre and post-surgery:** Attend Curtin Health & Wellness Centre at Curtin University to have a bone density scan and other physical measures of your back movement, back strength, upper back pain, breast size, posture and bra (see below). This is likely to take 1 hour.

Costs

Taking part in this research is voluntary. There are no costs involved in taking part and you can withdraw at any time.
Free parking will be available for all appointments.

The Benefits

As a participant in these two studies you will receive the following benefits:
- A printed copy of your bone mineral density results that you can take to your GP to discuss.
- Information on how to correctly fit your bra.

How to get involved

Interested in participating in study one or two or both? More information on the study and recruitment forms are available by contacting the principal investigator using the details below.

Contact Us

Linda Spencer
School of Physiotherapy & Exercise Science.
Curtin University
Bentley WA
08 9266 3666

Linda.spencer@postgrad.curtin.edu.au
www.backbreastbrastudy.net

317

Appendix 3h: Study promotion and recruitment material – bra fitting guide

References

1 McGhee DE, Steele JR & Munro BJ. (2010). Education improves bra knowledge and fit, and level of breast support in adolescent female athletes: A cluster-randomised trial. *Journal of Physiotherapy.* 56(1), 19–24.

2 McGhee DE & Steele JR. (2010). Optimising breast support in female patients through correct bra fit: A cross-sectional study. *Journal of Science and Medicine in Sport.* 13(6), 568–572.

3 Greenbaum AR, Heslop T, Morris J, Dunn KW. (2003). An investigation of the suitability of bra fit in women referred for reduction mammaplasty. *British Journal of Plastic Surgery.* 56(3), 230–236.

4 Mason BR, Page KA, Fallon K. (1999). An analysis of movement and discomfort of the female breast during exercise and the effects of breast support in three cases. *Journal of Science and Medicine in Sport.* 2(2), 134–144.

5 Robbins LB, Pender NJ, Kazanis AS. (2003). Barriers to physical activity perceived by adolescent girls. *Journal of Midwifery and Women's Health.* 48(3), 206–212.

6 McGhee DE, Steele JR & Munro BJ. (2008). Sports Bra Fitness. Wollongong NSW: Breast Research Australia (BRA), Biomechanics Research Laboratory, University of Wollongong: ISBN 9781741281552.

SPORTS MEDICINE AUSTRALIA

Exercise and breast support

A guide to understanding breast support during physical activity and how to determine correct bra fit

bra – breast research australia

University of Wollongong

A recent study found that 88% of female adolescents wore a bra during sport that did not fit correctly, while 85% failed a simple knowledge test on bras and bra fit[1]. This fact sheet aims to provide easy-to-understand information on how to choose a bra suitable for physical activity and to tell if it fits you properly. Hopefully this information will ensure that the next sports bra you buy is the right size, provides you with good support and, most importantly, is comfortable.

Why wear a supportive bra during physical activity?

Improve posture and performance

As breasts can be heavy, the force created by them can pull your trunk forward, making you slouch. This can negatively affect your athletic or sports performance, and lead to headaches and neck, back and arm pain[2,3].

Figure 1 Bad posture (left), good posture (right)

Fact...

16D breasts weigh approximately 600 grams each.

That's as much as 1.2 litres of milk hanging from the front of your chest.

Minimise breast movement

Research has shown that during activities such as running and jumping, bare breasts move up and down as much as 12 cm. This is due to insufficient anatomical support within your breasts[4].

Minimise breast discomfort and embarrassment

Excessive breast movement during exercise is often associated with breast discomfort and can be embarrassing for some females. As both of these factors have been shown to be barriers to physical activity[1,5], breast support should be made a priority and bras regarded as essential pieces of sporting equipment, rather than just underwear.

Figure 2 Breast movement during treadmill running when wearing a supportive bra compared to a non-supportive bra

High Support   Low Support
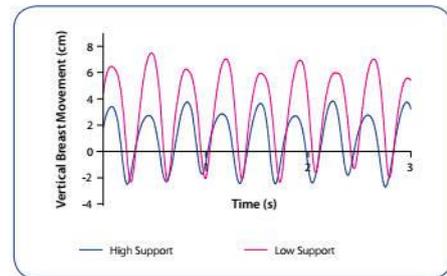
How much breast support do I need?

The amount of breast support needed varies with age, bra size and the type of exercise.

Age

Breasts are primarily supported by the skin covering them. Elasticity of the skin decreases with age which, in turn, reduces the support it can provide. This means that older women require greater support from their bras, especially after pregnancy.

Bra size

Females with larger bra sizes have heavier breasts and therefore require greater support from their bra[6].

Different types of exercise

Different types of exercises cause different breast movement. Exercises with more vertical movement of the body (e.g. horse riding compared to bike riding; jumping compared to walking) or movements involving rapid lower limb movement (e.g. running compared to walking) cause more breast movement and, therefore, require greater breast support[6].

Figure 3 Guide to the level of breast support required in relation to your age, bra cup size and the type of physical activity you are involved in. NB: This chart should be used as a guide only. Your level of breast support should be individually modified according to any breast discomfort and the amount of breast movement you experience when you are active. Personal circumstances, such as your menstrual cycle or changes in body weight, can affect the level of breast support you require.

		WALKING	JOGGING	RUNNING
15–29 YRS	A–B cup	●	● ▲	▲
	C–D cup	●	▲	▲
	≥ E cup	▲	▲ ■	■
30–45 YRS	A–B cup	●	● ▲	▲
	C–D cup	● ▲	▲	▲ ■
	≥ E cup	▲	■	■
46 YRS	A–B cup	●	▲	▲
	C–D cup	● ▲	▲ ■	▲ ■
	≥ E cup	▲	■	■

KEY: ● = Crop top ▲ = Sports bra ■ = Sports bra + Crop top

Tip...
Women with bra cup sizes D+ might require two bras (sports bra plus a crop top) to achieve enough support.

Which bra should I wear?

Types of bras

There are three basic types of bras to choose from:
- Fashion bras (bras worn during everyday activities)
- Crop tops (bras with no cups that compress both breasts together against the chest)
- Sports bras (bras with structured cups that are worn during physical activity)

Figure 4 Types of bras

Fashion bra: breasts not completely covered, thin straps, non-supportive material

Crop top, round neck: breasts covered, wide band, strong elastic material

Sports bra: breasts covered, wide padded straps, wide strong band

If only a low level of breast support is needed (e.g. if you are young, have small breasts and are walking), a crop top might provide sufficient breast support. However, if a high level of breast support is needed (e.g. if you are older, have large breasts and are running) a highly supportive sports bra or even two bras may be required (e.g. a sports bra and crop top) to achieve enough support[6].

How do I choose the right bra?

A supportive bra should minimise breast movement. Ideally your breasts should move in unison with your torso and not bounce excessively by themselves. The less they move, the better. However, some supportive bras can be uncomfortable. You need to try and ensure you have a supportive bra that is also comfortable to wear.

Band

Needs to be made of strong, wide elastic material so it can support your breasts without riding up. Larger bra sizes require wider bands.

Straps

Should be wide and padded for comfort so they don't dig into your shoulders.

Cup

Your breasts MUST be completely covered or encased in the cups to effectively limit breast movement.

Underwire

If a bra has underwire it MUST fit the shape of your breasts correctly. Soft breast tissue is not designed to tolerate underwire digging into it. If it is not possible to find an underwire bra that fits correctly, choose a non-underwire (soft-cup) bra instead.

Front band

The centre of the bra between the cups should sit on your breast bone, not on your breast tissue.

Material

Should be able to wick sweat away from your body to keep you cool but not irritate your skin. Crop tops should be made of strong elastic material that can compress your breasts firmly against your chest.

Fact...

Research has found many females wear bras that are past their used by date, where the elastic is stretched and the material is worn. Are you one of them?

Why is correct bra fit important?

Any supportive bra MUST fit correctly. If it doesn't fit, it won't provide adequate support. Ill-fitting bras contribute to neck, back and arm pain, especially in females with larger breasts[2], so make sure your bra fits you well.

Three easy steps... to correct bra fit

1. Fit the band correctly first, ensuring all of your breast, especially under your armpit is in the cups.
2. Adjust the straps, then check for any wrinkles/gaps or bulging of the cups and go up or down a cup size accordingly.
3. Check the underwire fits your breast shape correctly. If not, start these steps again with a different bra.

Figure 5 Correct bra fit

Bra fit checklist

☐ **Band** – Not too tight; no flesh bulging over the top of the band (i.e. too small); doesn't ride up when your arms are raised (i.e. too big). Ideally you should fasten a new bra on the loosest hook so you can tighten it up as the bra stretches with age.

☐ **Straps** – Comfortable, not digging in; not sliding off.

☐ **Cup** – No breast bulge over the top of the cup (too small); no wrinkles or gaps in the cup (too big).

☐ **Underwire** – Sits on your ribs, not on your breast tissue at the front or under your armpits (too small or the design does not fit your breast shape).

☐ **Front band** – Sits flat against your breast bone.

Appendix 4a: Participant information questionnaire

Back Breast & Bra
Study

Curtin University

Participant Information Questionnaire

Welcome to the Back, Breast and Bra study. By completing this questionnaire you acknowledge that you have read the participant information sheet provided and agree to participate in the back, breast and bra study. This questionnaire will collect information about you, your body and your bra which will be used in research led by Linda Spencer at Curtin University (linda.spencer@postgad.curtin.edu.au). Your honesty and accuracy with answering **all** of the questions is appreciated. You have the choice to complete the survey anonymously. If you choose to provide your contact details you agree to be contacted by the researcher about possible further involvement in the study. The information you provide in this form will be confidential and de-identified once submitted

Yes, I consent and would like to provide my contact details   ☐   (please enter details below)
Yes, I consent and would like to complete the questionnaire anonymously   ☐   (please go to question 1)
No, I do not consent   ☐   (Thank you for your consideration)

Contact Details (optional)	
Name: _____	Address: _____
Phone: _____	Email: _____

Personal Details	
Age: _____	Height _____
Weight: _____	Bra size: _____

About You

1. Have you ever had any of the following:
   - ☐ Breast surgery
   - ☐ A diagnosed breast condition specify: _____
   - ☐ Thoracic spine surgery
   - ☐ Autoimmune disease (e.g. rheumatoid arthritis; ankylosing spondylitis)
   - ☐ Cancer involving the bones
   - ☐ Neurodegenerative disorder (e.g. multiple sclerosis; stroke; Parkinson's disease)
   - ☐ Lung condition
   - ☐ Thoracic spine condition
   - ☐ Inflammatory disease
   - ☐ Long term use of steroids or pain-killers

   - ☐ None of the above

2. Have you had breast reduction surgery?
   ☐ Yes (go to question 3)
   ☐ No, but I am awaiting breast reduction surgery (go to question 3)
   ☐ No, and I am not awaiting breast reduction surgery (go to question 4)

3. What reasons have led you to undergo breast reduction surgery?

   _____
   _____
   _____

4. Do you have an occupation?
   ☐ Yes I work full time (go to question 5)
   ☐ Yes I work part time (go to question 5)
   ☐ No (go to question 6)

5. What kind of job do you have?
   ☐ A sedentary job
   ☐ A reasonably active job
   ☐ A very active job

6. Rate your health
   ☐ Poor
   ☐ Average
   ☐ Good
   ☐ Excellent

7. Rate your fitness
   ☐ Poor
   ☐ Average
   ☐ Good
   ☐ Excellent

8. What is your menopausal status:
   ☐ I am *pre-menopausal* and still menstruating regularly (go to question 10)
   ☐ I am pre-menopausal because I continue to take hormonal contraceptive medication or have another form of contraceptive method (IUD/implant) (go to question 10).
   ☐ I am *peri-menopausal*. I have had a period in the previous 3 months but over the past 12 months my periods have become irregular (go to question 10)
   ☐ I am post-menopausal. I have not had a period in the previous 12 months (go to question 9)

9. Do you think your breasts changed during or following menopause?
- ☐ Yes they got bigger
- ☐ Yes they changed shape
- ☐ Yes they got smaller
- ☐ Yes they became more sensitive
- ☐ Yes they started to hurt
- ☐ No

10. How active are you?
- ☐ Inactive
- ☐ Occasionally active
- ☐ Regularly active
- ☐ Very active

About your body

---

11. In the past month have you experienced upper back pain in the region shaded yellow in this picture?
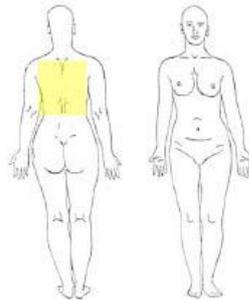
- ☐ Yes (go to question 12)
- ☐ No (go to question 15)
- ☐ Sometimes (go to question 12)

12. In the past month how would you rate this pain? (circle or state the appropriate number)

0	1	2	3	4	5	6	7	8	9	10

No pain   Worst pain imaginable

Participant Information Questionnaire

13. How long have you experienced upper back pain?
- ☐ month
- ☐ 1-3 months
- ☐ 4-12 months
- ☐ More than a year

14. Have you received treatment for your upper back pain?
- ☐ Yes, I have seen a health professional for treatment
- ☐ No

15. A. How satisfied are you with your body shape? (Circle a number below)

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Completely dissatisfied   completely satisfied

B. If you circled a number **less than 10**, if you had the chance what would you change?
- ☐ My breasts
- ☐ My waist
- ☐ My hips
- ☐ My legs
- ☐ My whole top
- ☐ My whole bottom
- ☐ My whole body
- ☐ Other (please specify) _____

About your breasts

---

16. Are you embarrassed about your breasts?
- ☐ Yes
- ☐ No

17. If you had the chance to change your breasts how would you do so?
- ☐ Make them bigger
- ☐ Make them smaller
- ☐ Change their shape

18. Do you think your breast size affects the rest of your body?
- ☐ Yes it makes my posture worse
- ☐ Yes it causes me upper back pain
- ☐ Yes it causes me neck pain
- ☐ Yes it causes me lower back pain
- ☐ Yes it causes me to experience breast discomfort when exercising
- ☐ Yes it makes my shoulders hurt
- ☐ Yes it makes it hard to breathe
- ☐ Yes it causes me to be self-conscious
- ☐ Yes it makes anxious
- ☐ No I don't think my breast size affects any other part of my body

---

About your bra

---

19. Which statement bests describes your bra wearing habits
- ☐ I wear a bra everyday (go to question 20)
- ☐ I only wear a bra occasionally (go to question 22)
- ☐ I never wear a bra, and never have (questionnaire completed, thank you)

20. How do you put your bra on?
- ☐ Over my head
- ☐ Step into it
- ☐ Strap it behind my back
- ☐ Strap in the front and spin it around
- ☐ I don't have straps, I just put it on

21. When you buy a new bra, do you have your bra fitted?
- ☐ Yes (go to question 23)
- ☐ No (go to question 22)

22. I don't have my bra fitted regularly or at all because:
- ☐ Pressure by the fitter/shop to buy a certain bra
- ☐ Expense of fitting procedure
- ☐ Not available locally
- ☐ Feeling of embarrassment
- ☐ Never thought to
- ☐ Other (specify) _____

23. What is important to you when purchasing a bra
    ☐ Price
    ☐ Brand
    ☐ Appearance/design
    ☐ Special offers
    ☐ Comfort
    ☐ Colours
    ☐ Cup shape
    ☐ Function
    ☐ Advertising
    ☐ Other people's recommendations

24. What type of bra do you prefer?
    ☐ Minimiser (a bra which makes your breasts look smaller)
    ☐ Padded (a bra that had padding in the cups)
    ☐ Push-up (a bra that creates the appearance of increased cleavage)
    ☐ Sports (a sturdier bra offering greater support for physical activity)
    ☐ Strapless (a bra without shoulder straps)
    ☐ Other (specify) _____
    ☐ Depends on the activity/event/occasion
    ☐ I have no preference

25. How often do you shop for bras?
    ☐ Every month
    ☐ Once in three months
    ☐ Once in six months
    ☐ Once a year
    ☐ Every few years

26. When is it time to buy a new bra?
    ☐ When there is a special occasion
    ☐ When they are on sale
    ☐ When I have washed my bra more than 20 times
    ☐ When my previous one breaks or gets tatty
    ☐ When I start finding my current bra uncomfortable

27. How satisfied are you with your bra fit
    ☐ Completely satisfied, my bra fits me very well (questionnaire complete, thank you)
    ☐ Unsatisfied, I struggle to make a bra fit well (go to question 28)

28. Which of the following describes your dissatisfaction with your bra fit
    - ☐ The straps dig in
    - ☐ My breasts spill over the sides
    - ☐ My bra rides up my back
    - ☐ My bra is too tight around the sides and back
    - ☐ My bra causes skin irritation
    - ☐ The underwire is uncomfortable
    - ☐ The straps don't stay up on my shoulders
    - ☐ The cups are too big
    - ☐ Other (specify) _____

Questionnaire complete. Thank you

Appendix 4b: Breast size score conversion chart (version 2)

	Cup Size	Band size (under-bust circumference, cm)									
		8 (63-67)	10 (68-72)	12 (73-77)	14 (78-82)	16 (83-87)	18 (88-92)	20 (93-97)	22 (98-102)	24 (103-107)	26 (108-112)
	AA	0 (75-77)	1 (80-82)	2 (85-87)	3 (90-92)	4 (95-97)	5 (100-102)	6 (105-107)	7 (110-112)	8 (115-117)	9 (120-122)
	A	1 (77-79)	2 (82-84)	3 (87-89)	4 (92-94)	5 (97-99)	6 (102-104)	7 (107-109)	8 (112-114)	9 (117-119)	10 (122-124)
	B	2 (79-81)	3 (84-86)	4 (89-91)	5 (94-96)	6 (99-101)	7 (104-106)	8 (109-111)	9 (114-116)	10 (119-121)	11 (124-126)
Breast size score (over-bust circumference, cm)	C	3 (81-83)	4 (86-88)	5 (91-93)	6 (96-98)	7 (101-103)	8 (106-108)	9 (111-113)	10 (116-118)	11 (121-123)	12 (126-128)
	D	4 (83-85)	5 (88-90)	6 (93-95)	7 (98-100)	8 (103-105)	9 (108-110)	10 (113-115)	11 (118-120)	12 (123-125)	13 (128-130)
	DD	5 (85-87)	6 (90-92)	7 (95-97)	8 (100-102)	9 (105-107)	10 (110-112)	11 (115-117)	12 (120-122)	13 (125-127)	14 (130-132)
	E	6 87-89)	7 (92-94)	8 (97-99)	9 (102-104)	10 (107-109)	11 (112-114)	12 (117-119)	13 (122-124)	14 (127-129)	15 (132-134)
	F	7 (89-91)	8 (94-96)	9 (99-101)	10 (104-106)	11 (109-111)	12 (114-116)	13 (119-121)	14 (124-126)	15 (129-131)	16 (134-136)
	G	8 (91-93)	9 (96-98)	10 (101-103)	11 (106-108)	12 (111-113)	13 (116-118)	14 (121-123)	15 (126-128)	16 (131-133)	17 (136-138)
	H	9 (93-95)	10 (98-100)	11 (103-105)	12 (108-110)	13 (113-115)	14 (118-120)	15 (123-125)	16 (128-130)	17 (133-135)	18 (138-140)

Breast size score bra conversion chart. To determine a breast size score first identify the correct bra size (band and cup size). Establish the correct band size by measuring around the body, directly below the bust (under-bust circumference) and the correct cup size by measuring across the fullest part of the breasts whilst wearing a bra (over-bust circumference) [218]. Use the top row of the table to select the band size, this increases from left to right. Then use the first column of the table to select the cup size, this increases from top to bottom. Track down and across to find the table cell where these two selections intersect. Breast size score is shown in bolded text.

Appendix 4c: BREAST-Q version 1.0 reduction module (preoperative)

BREAST-Q™
REDUCTION / MASTOPEXY MODULE (PRE OPERATIVE) 1.0

After reading each question, please circle the number in the box that best describes your situation. If you are unsure how to answer a question, choose the answer that comes closest to how you feel. Please answer all questions.

1. With your breasts in mind, in the past 2 weeks, how <u>satisfied or dissatisfied</u> have you been with:

		Very Dissatisfied	Somewhat Dissatisfied	Somewhat Satisfied	Very Satisfied
a.	How your breasts look in clothes?	1	2	3	4
b.	How your breast size matches the rest of your body?	1	2	3	4
c.	The size of your breasts?	1	2	3	4
d.	The shape of your breasts when you are wearing a bra?	1	2	3	4
e.	How equal in size your breasts are to each other?	1	2	3	4
f.	How comfortably your bras fit?	1	2	3	4
g.	The shape of your breasts when you are <u>not</u> wearing a bra?	1	2	3	4
h.	How you look in the mirror <u>clothed</u>?	1	2	3	4
i.	How your breasts sit/hang on your chest?	1	2	3	4
j.	How normal your breasts look?	1	2	3	4
k.	How you look in the mirror <u>unclothed</u>?	1	2	3	4

Please check that you have answered all the questions before going on to the next page

2. With your breasts in mind, in the past 2 weeks, how often have you felt:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time
a.	Confident in a social setting?	1	2	3	4	5
b.	Of equal worth to other women?	1	2	3	4	5
c.	Good about yourself?	1	2	3	4	5
d.	Self-assured?	1	2	3	4	5
e.	Confident in your clothes?	1	2	3	4	5
f.	Accepting of your body?	1	2	3	4	5
g.	That your appearance matches who you are inside?	1	2	3	4	5
h.	Confident about your body?	1	2	3	4	5
i.	Attractive?	1	2	3	4	5

3. Thinking of your sexuality, how often do you generally feel:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time	Not Applicable
a.	Comfortable/at ease during sexual activity?	1	2	3	4	5	N/A
b.	Confident sexually?	1	2	3	4	5	N/A
c.	Satisfied with your sex life?	1	2	3	4	5	N/A
d.	Sexually attractive in your clothes?	1	2	3	4	5	N/A
e.	Sexy when unclothed?	1	2	3	4	5	N/A

Please check that you have answered all the questions before going on to the next page

331

BREAST-Q™
REDUCTION / MASTOPEXY MODULE (PRE OPERATIVE) 1.0

4. In the past 2 weeks, <u>how often</u> have you experienced:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time
a.	Headaches?	1	2	3	4	5
b.	Pain in your breast area?	1	2	3	4	5
c.	Lack of energy?	1	2	3	4	5
d.	Difficulty doing vigorous physical activities (e.g. running or exercising)?	1	2	3	4	5
e.	Feeling physically unbalanced?	1	2	3	4	5
f.	Shoulder pain?	1	2	3	4	5
g.	Difficulty sleeping because of discomfort in your breast area?	1	2	3	4	5
h.	Neck pain?	1	2	3	4	5
i.	Painful gouges or grooves in your shoulders from your bra straps?	1	2	3	4	5
j.	Feeling physically uncomfortable?	1	2	3	4	5
k.	Rashes under your breasts?	1	2	3	4	5
l.	Back pain?	1	2	3	4	5
m.	Arm pain?	1	2	3	4	5
n.	Pain, numbness or tingling in your hands because of your breast size?	1	2	3	4	5

Please check that you have answered all the questions

BREAST-Q-ReductionMastopexyModule-Preoperative_AU1.0_eng-USofl

3

Pusic AL, Klassen AF, Scott AM, Klok JA, Cordeiro PG, Cano SJ. Development of a new patient-reported outcome measure for breast surgery: the BREAST-Q. Plast Reconstr Surg. 2009;124(2):345-53

Appendix 4d: BREAST-Q version 2.0 reduction module (postoperative)

BREAST-Q™
REDUCTION MODULE (POST OPERATIVE) 2.0

The following questions are about your breasts and breast surgery. After reading each question, please circle the number in the box that best describes your situation. If you are unsure how to answer a question, choose the answer that comes closest to how you feel. Please answer all questions.

1. With your breasts in mind, in the past 2 weeks, how <u>satisfied or dissatisfied</u> have you been with:

		Very Dissatisfied	Somewhat Dissatisfied	Somewhat Satisfied	Very Satisfied
a.	How your breasts look in clothes?	1	2	3	4
b.	How your breast size matches the rest of your body?	1	2	3	4
c.	The size of your breasts?	1	2	3	4
d.	The shape of your breasts when you are wearing a bra?	1	2	3	4
e.	How equal in size your breasts are to each other?	1	2	3	4
f.	How comfortably your bras fit?	1	2	3	4
g.	The shape of your breasts when you are <u>not</u> wearing a bra?	1	2	3	4
h.	How you look in the mirror <u>clothed</u>?	1	2	3	4
i.	How your breasts sit/hang on your chest?	1	2	3	4
j.	How normal your breasts look?	1	2	3	4
k.	The location of your scars?	1	2	3	4
l.	How your scars look?	1	2	3	4
m.	How you look in the mirror <u>unclothed</u>?	1	2	3	4

Please check that you have answered all the questions before going on to the next page

BREAST-Q – Reduction Module-postoperative – United States/English – Original version
BREAST-Q-Reduction-Post_AU2.0_eng-USorI.doc

333

BREAST-Q™
REDUCTION MODULE (POST OPERATIVE) 2.0

2. We would like to know how you feel about the <u>outcome</u> of your breast surgery. Please indicate how much you agree or disagree with each statement:

		Disagree	Somewhat Agree	Definitely Agree
a.	Having surgery was the right decision for me.	1	2	3
b.	I would encourage other women in my situation to have breast reduction surgery.	1	2	3
c.	I would do it again.	1	2	3
d.	Overall the surgery was a positive experience.	1	2	3
e.	Having surgery changed my life for the better.	1	2	3
f.	I have no regrets about having surgery.	1	2	3
g.	The outcome perfectly matched my expectations.	1	2	3
h.	It turned out exactly as I had planned.	1	2	3

Please check that you have answered all the questions before going on to the next page

2

334

BREAST-Q™
REDUCTION MODULE (POST OPERATIVE) 2.0

3. With your breasts in mind, in the past 2 weeks, how often have you felt:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time
a.	Confident in a social setting?	1	2	3	4	5
b.	Of equal worth to other women?	1	2	3	4	5
c.	Good about yourself?	1	2	3	4	5
d.	Self-assured?	1	2	3	4	5
e.	Confident in you clothes?	1	2	3	4	5
f.	Accepting of your body?	1	2	3	4	5
g.	That your appearance matches who you are inside?	1	2	3	4	5
h.	Confident about your body?	1	2	3	4	5
i.	Attractive?	1	2	3	4	5

4. Thinking of your sexuality, since your breast reduction, how often do you generally feel:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time	Not Applicable
a.	Comfortable/at ease during sexual activity?	1	2	3	4	5	N/A
b.	Confident sexually?	1	2	3	4	5	N/A
c.	Satisfied with your sex life?	1	2	3	4	5	N/A
d.	Sexually attractive in your clothes?	1	2	3	4	5	N/A
e.	Sexy when underclothed?	1	2	3	4	5	N/A

Please check that you have answered all the questions before going on to the next page

BREAST-Q – Reduction Module-postoperative – United States/English – Original version
BREAST-Q-Reduction-Post_AU2.0_eng-USorl.doc

5. In the past 2 weeks, <u>how often</u> have you experienced:

		None of the time	A little of the time	Some of the time	Most of the time	All of the time
a.	Headaches?	1	2	3	4	5
b.	Pain in your breast area?	1	2	3	4	5
c.	Lack of energy?	1	2	3	4	5
d.	Difficulty doing vigorous physical activities (e.g. running or exercising)?	1	2	3	4	5
e.	Feeling physically unbalanced?	1	2	3	4	5
f.	Shoulder pain?	1	2	3	4	5
g.	Difficulty sleeping because of discomfort in your breast area?	1	2	3	4	5
h.	Neck pain?	1	2	3	4	5
i.	Painful gouges or grooves in your shoulders from your bra straps?	1	2	3	4	5
j.	Feeling physically uncomfortable?	1	2	3	4	5
k.	Rashes under your breasts?	1	2	3	4	5
l.	Back pain?	1	2	3	4	5
m.	Arm pain?	1	2	3	4	5
n.	Pain, numbness or tingling in your hands because of your breast size?	1	2	3	4	5

Please check that you have answered all the questions before going on to the next page

6. How <u>satisfied or dissatisfied</u> were you with the <u>information</u> you received from your plastic surgeon about:

		Very Dissatisfied	Somewhat Dissatisfied	Somewhat Satisfied	Very Satisfied
a.	How the surgery was to be done?	1	2	3	4
b.	Possible complications?	1	2	3	4
c.	Healing and recovery time?	1	2	3	4
d.	How to choose a breast size that would suit what you wanted?		2	3	4
e.	The potential for loss of sensation in your nipples?	1	2	3	4
f.	What size you could expect your breasts to be after surgery?	1	2	3	4
g.	Potential for loss of blood supply to your nipple area?	1	2	3	4
h.	How to care for your incisions after surgery?	1	2	3	4
i.	What you could expect your breasts to look like after surgery?	1	2	3	4
j.	What the scars would look like?	1	2	3	4
k.	How the surgery could affect future breast cancer screening (e.g. mammogram, self-examinations)?	1	2	3	4
l.	Options to help with scarring?	1	2	3	4
m.	How the surgery could affect breast-feeding? (only answer if applicable)	1	2	3	4

7. In the past 2 weeks, how <u>satisfied or dissatisfied</u> were you with:

		Very Dissatisfied	Somewhat Dissatisfied	Somewhat Satisfied	Very Satisfied
a.	How high or low your nipples are on your breasts?	1	2	3	4
b.	How your nipples are lined up in relation to each other?	1	2	3	4
c.	The shape of your nipples and areolas?	1	2	3	4
d.	How your nipples and areolas look?	1	2	3	4
e.	The amount of sensation (feeling) in your nipples?	1	2	3	4

Please check that you have answered all the questions before going on to the next page

5

Pusic AL, Klassen AF, Scott AM, Klok JA, Cordeiro PG, Cano SJ. Development of a new patient-reported outcome measure for breast surgery: the BREAST-Q. Plast Reconstr Surg. 2009;124(2):345-53

Appendix 4e: Human Activity Profile

338

Dear HAP requestor,

We are sending you a copy of the HAP and some abbreviated information from our manual. You are granted permission to use the scale in your research studies. However, you are not given permission to re-transmit this scale to other people.

Thank you for your interest in the HAP.

Sincerely,

David Daughton, M.S.
Behavioral Researcher
University of Nebraska Medical Center

DD/sm

HUMAN ACTIVITY PROFILE

Instructions

Please check each activity according to these directions:

Check Column 1 ("Still Doing This Activity") if:

You completed the activity unassisted the last time you had the need or opportunity to do so.

Check Column 2 ("Have Stopped Doing This Activity") if:

You have engaged in the activity in the past, but you probably would not perform the activity today even if the opportunity should arise.

Check Column 3 ("Never Did This Activity") if:

You have never engaged in the specific activity.

Human Activity Profile Test
By David M. Daughton and A. James Fix, Ph.D.

Name_____ Age____ Male____ Female____ Smoker_____ Non-Smoker____
(Optional)
Occupation_____ Married____ Single____ Separated/Divorced_____

Any chronic ailments? Yes____ No____ Highest school grade completed_____

	Still Doing This Activity	Have Stopped Doing This Activity	Never Did This Activity
1. Getting in and out of chairs or bed (without assistance)			
2. Listening to the radio			
3. Reading books, magazines or newspapers			
4. Writing (letters, notes)			
5. Working at a desk or table			
6. Standing (for more than one minute)			
7. Standing (for more than five minutes)			
8. Dressing or undressing (without assistance)			
9. Getting clothes from drawers or closets			
10. Getting in or out of a car (without assistance)			
11. Dining at a restaurant			
12. Playing cards/table games			
13. Taking a bath (no assistance needed)			
14. Putting on shoes, stockings or socks (no rest or break needed)			
15. Attending a movie, play, church event or sports activity			
16. Walking 30 yards (27 meters)			
17. Walking 30 yards (non-stop)			

© 1980

Human Activity Profile Test

	Still Doing This Activity	Have Stopped Doing This Activity	Never Did This Activity
18. Dressing/undressing (no rest or break needed)			
19. Using public transportation or driving a car (99 miles or less)			
20. Using public transportation or driving a car (100 miles or more)			
21. Cooking your own meals			
22. Washing or drying dishes			
23. Putting groceries on shelves			
24. Ironing or folding clothes			
25. Dusting/polishing furniture or polishing cars			
26. Showering			
27. Climbing six steps			
28. Climbing six steps (non-stop)			
29. Climbing nine steps			
30. Climbing 12 steps			
31. Walking ½ block on level ground			
32. Walking ½ block on level ground (non-stop)			
33. Making a bed (not changing sheets)			
34. Cleaning windows			
35. Kneeling, squatting to do light work			
36. Carrying a light load of groceries			
37. Climbing nine steps (non-stop)			

Human Activity Profile Test

	Still Doing This Activity	Have Stopped Doing This Activity	Never Did This Activity
38. Climbing 12 steps (non-stop)			
39. Walking ½ block uphill			
40. Walking ½ block uphill (non-stop)			
41. Shopping (by yourself)			
42. Washing clothes (by yourself)			
43. Walking one block on level ground			
44. Walking two blocks on level ground			
45. Walking one block on level ground (non-stop)			
46. Walking two blocks on level ground (non-stop)			
47. Scrubbing (floors, walls or cars)			
48. Making beds (changing sheets)			
49. Sweeping			
50. Sweeping (five minutes non-stop)			
51. Carrying a large suitcase or bowling (one game)			
52. Vacuuming carpets			
53. Vacuuming carpets (five minutes non-stop)			
54. Painting (interior/exterior)			
55. Walking six blocks on level ground			
56. Walking six blocks on level ground (non-stop)			
57. Carrying out the garbage			

Human Activity Profile Test

	Still Doing This Activity	Have Stopped Doing This Activity	Never Did This Activity
58. Carrying a heavy load of groceries			
59. Climbing 24 steps			
60. Climbing 36 steps			
61. Climbing 24 steps (non-stop)			
62. Climbing 36 steps (non-stop)			
63. Walking one mile			
64. Walking one mile (non-stop)			
65. Running 110 yards (100 meters) or playing softball/baseball			
66. Dancing (social)			
67. Doing calisthenics or aerobic dancing (5 minutes non-stop)			
68. Mowing the lawn (power mower, but not a riding mower)			
69. Walking two miles			
70. Walking two miles (non-stop)			
71. Climbing 50 steps (2½ floors)			
72. Shoveling, digging or spading			
73. Shoveling, digging or spading (five minutes non-stop)			
74. Climbing 50 steps (non-stop)			
75. Walking three miles or golfing 18 holes without a riding cart			
76. Walking three miles (non-stop)			
77. Swimming 25 yards			

Human Activity Profile Test

	Still Doing This Activity	Have Stopped Doing This Activity	Never Did This Activity
78. Swimming 25 yards (non-stop)			
79. Bicycling one mile			
80. Bicycling two miles			
81. Bicycling one mile (non-stop)			
82. Bicycling two miles (non-stop)			
83. Running or jogging ¼ mile			
84. Running or jogging ½ mile			
85. Playing tennis or racquetball			
86. Playing basketball/soccer (game play)			
87. Running or jogging ¼ mile (non-stop)			
88. Running or jogging ½ mile (non-stop)			
89. Running or jogging one mile			
90. Running or jogging two miles			
91. Running or jogging three miles			
92. Running or jogging one mile in 12 minutes or less			
93. Running or jogging two miles in 20 minutes or less			
94. Running or jogging three miles in 30 minutes or less			

345

Appendix 4f: Medical Outcomes Study Short-Form 36 Health survey

Appendix A: SF-36 Version 2 (modified for Australian use*)

The SF-36v2   Health Survey

Instructions for Completing the Questionnaire

Please answer every question. Some questions may look like others, but each one is different. Please take the time to read and answer each question carefully by filling in the bubble that best represents your response.

EXAMPLE

This is for your review. Do not answer this question. The questionnaire begins with the section Your Health in General below.

For each question you will be asked to fill in a bubble in each line:

1. How strongly do you agree or disagree with each of the following statements?

	Strongly agree	Agree	Uncertain	Disagree	Strongly disagree
a) I enjoy listening to music	O	O	O	O	O
B) I enjoy reading magazines	O	O	O	O	O

Please begin answering the questions now, there are eleven questions

		Your Health in General	

1. In general, would you say your health is:

Excellent	Very good	Good	Fair	Poor
O	O	O	O	O

2. Compared to one year ago, how would you rate your health in general now?

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago
O	O	O	O	O

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
a) **Vigorous activities,** such as running, lifting heavy objects, participating in strenuous sports	O	O	O
b) **Moderate activities,** such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	O	O	O
c) Lifting or carrying groceries	O	O	O
d) Climbing **several** flights of stairs	O	O	O
e) Climbing **one** flight of stairs	O	O	O
f) Bending, kneeling, or stooping	O	O	O
g) Walking **more than a kilometre**	O	O	O
h) Walking **several hundred metres**	O	O	O
i) Walking **one hundred metres**	O	O	O
j) Bathing or dressing yourself	O	O	O

8. During the past <u>4 weeks</u>, how much did <u>pain</u> interfere with your normal work (including both work outside the home and housework)?

Not at all	Slightly	Moderately	Quite a bit	Extremely
O	O	O	O	O

9. These questions are about how you feel and how things have been with you <u>during the past 4 weeks</u>. For each question, please give the one answer that comes closest to the way you have been feeling. How much of the time during the <u>past 4 weeks</u>?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a) Did you feel full of life?	O	O	O	O	O
b) Have you been very nervous?	O	O	O	O	O
c) Have you felt so down in the dumps that nothing could cheer you up?	O	O	O	O	O
D) Have you felt calm and peaceful?	O	O	O	O	O
e) Did you have lots of energy?	O	O	O	O	O
f) Have you felt downhearted and depressed?	O	O	O	O	O
g) Did you feel worn out?	O	O	O	O	O
h) have you been happy?	O	O	O	O	O
i) Did you feel tired?	O	O	O	O	O

10. During the <u>past 4 weeks</u>, how much of the time has your <u>physical health or emotional problems</u> interfered with you social activities (like visiting friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
O	O	O	O	O

348

11. How TRUE or FALSE is <u>each</u> of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
a) I seem to get sick a little easier than other people	O	O	O	O	O
b) I am as healthy as anybody I know	O	O	O	O	O
c) I expect my health to get worse	O	O	O	O	O
d) My health is excellent	O	O	O	O	O

Appendix 4g: Neck Disability Index

NECK DISABILITY INDEX

This questionnaire has been designed to give your therapist information as to how your neck pain has affected your ability to manage in everyday life. Please answer every section and mark in each section only the ONE box which applies to you. We realize you may feel that two of the statements may describe your condition, but please mark only the line which most closely describes your current condition.

Section 1 - Pain Intensity
- ☐ I have no pain at the moment.
- ☐ The pain is very mild at the moment.
- ☐ The pain is moderate at the moment.
- ☐ The pain is fairly severe at the moment.
- ☐ The pain is very severe at the moment.
- ☐ The pain is the worst imaginable at the moment.

Section 2 - Personal Care (Washing, Dressing, etc.)
- ☐ I do not have to change the way I wash and dress myself to avoid pain.
- ☐ I do not normally change the way I wash or dress myself even though it causes some pain.
- ☐ Washing and dressing increases my pain, but I can do it without changing my way of doing it.
- ☐ Washing and dressing increases my pain, and I find it necessary to change the way I do it.
- ☐ Because of my pain I am partially unable to wash and dress without help.
- ☐ Because of my pain I am completely unable to wash or dress without help.

Section 3 - Lifting
- ☐ I can lift heavy weights without increased pain.
- ☐ I can lift heavy weights but it causes increased pain
- ☐ Pain prevents me from lifting heavy weights off of the floor, but I can manage if they are conveniently positioned (e.g. on a table, etc.).
- ☐ Pain prevents me from lifting heavy weights off the floor, but I can manage light to medium weights if they are conveniently positioned.
- ☐ I can lift only very light weights.
- ☐ I cannot lift or carry anything at all.

Section 4 - Reading
- ☐ I can read as much as I want to with no pain in my neck.
- ☐ I can read as much as I want to with slight pain in my neck.
- ☐ I can read as much as I want with moderate pain in my neck.
- ☐ I can't read as much as I want because of moderate pain in my neck.
- ☐ I can hardly read at all because of severe pain in my neck.
- ☐ I cannot read at all.

Section 5 - Headache
- ☐ I have no headache at all.
- ☐ I have slight headaches which come infrequently.
- ☐ I have moderate headaches which come infrequently.
- ☐ I have moderate headaches which come frequently.
- ☐ I have severe headaches which come frequently.
- ☐ I have headaches almost all the time.

Section 6 - Concentration
- ☐ I can concentrate fully when I want to with no difficulty.
- ☐ I can concentrate fully when I want to with slight difficulty.
- ☐ I have a fair degree of difficulty in concentrating when I want to.
- ☐ I have a lot of difficulty in concentrating when I want to.
- ☐ I have a great deal of difficulty in concentrating when I want to.
- ☐ I cannot concentrate at all.

Section 7 - Work
- ☐ I can do as much as I want to.
- ☐ I can only do my usual work but no more.
- ☐ I can do most of my usual work, but no more.
- ☐ I cannot do my usual work.
- ☐ I can hardly do any work at all.
- ☐ I can't do any work at all.

Section 8 - Driving
- ☐ I can drive my car without any neck pain.
- ☐ I can drive my car as long as I want with slight pain in my neck.
- ☐ I can drive my car as long as I want with moderate pain in my neck.
- ☐ I can't drive my car as long as I want because of moderate pain in my neck.
- ☐ I can hardly drive at all because of severe pain in my neck.
- ☐ I can't drive my car at all.

Section 9 - Sleeping
- ☐ I have no trouble sleeping.
- ☐ My sleep is slightly disturbed (less than 1 hour sleep loss).
- ☐ My sleep is mildly disturbed (1-2 hour sleep loss).
- ☐ My sleep is moderately disturbed (2-3 hours sleep loss).
- ☐ My sleep is greatly disturbed (3-5 hours sleep loss).
- ☐ My sleep is completely disturbed (5-7 hours sleep loss).

Section 10 - Recreation
- ☐ I am able to engage in all my recreational activities with no neck pain at all.
- ☐ I am able to engage in all my recreational activities with some pain in my neck.
- ☐ I am able to engage in most but not all of my usual recreational activities because of pain in my neck.
- ☐ I am able to engage in a few of my usual recreational activities because of pain in my neck.
- ☐ I can hardly do any recreational activities because of pain in my neck.
- ☐ I can't do any recreational activities at all.

Vernon H, Mior S. The Neck Disability Index: A Study of Reliability and Validity. J Manipulative Physiol Ther. 1991; 14(7): 409-415

Appendix 4h: Shoulder pain assessment (participant information questionnaire addition)

In the past 4 weeks, have you experienced shoulder pain in the region highlighted in yellow in the picture below?

Yes ☐
No ☐
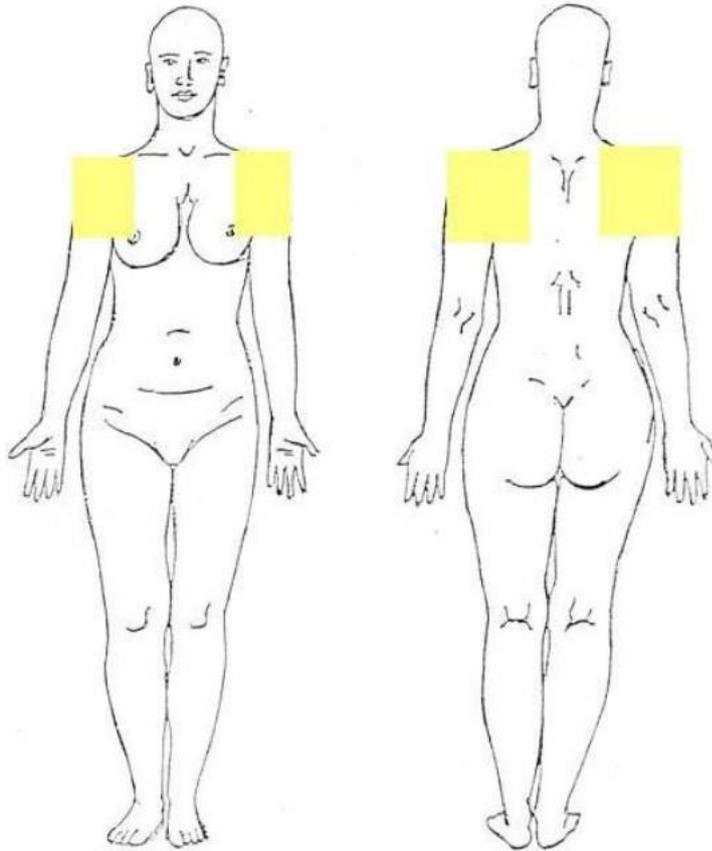
Rate the pain in your shoulders

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

No Pain   Worst pain imaginable

Appendix 4i: Orebro Musculoskeletal Pain Screening Questionnaire Short Form (OMPSQ)

1. How long have you had your current pain problem? Tick (√) one.
☐ 0-1 weeks [1] ☐ 1-2 weeks [2] ☐ 3-4 weeks [3] ☐ 4-5 weeks [4] ☐ 6-8 weeks [5]
☐ 9-11 weeks [6] ☐ 3-6 months [7] ☐ 6-9 months [8] ☐ 9-12 months [9] ☐ over 1 year [10]

2. How would you rate the pain that you have had during the past week? Circle one.

0   1   2   3   4   5   6   7   8   9   10   [   ]
No pain   *Pain as bad as it could be*

For items 3 and 4, please circle the one number that best describes your current ability to participate in each of these activities.

3. I can do light work (or home duties) for an hour.

0   1   2   3   4   5   6   7   8   9   10   (10-)[   ]
Not at all   *Without any difficulty*

4. I can sleep at night.

0   1   2   3   4   5   6   7   8   9   10   (10-)[   ]
Not at all   *Without any difficulty*

5. How tense or anxious have you felt in the past week? Circle one.

0   1   2   3   4   5   6   7   8   9   10   [   ]
Absolutely calm and relaxed   *As tense and anxious as I've ever felt*

6. How much have you been bothered by feeling depressed in the past week? Circle one.

0   1   2   3   4   5   6   7   8   9   10   [   ]
Not at all   *Extremely*

7. In your view, how large is the risk that your current pain may become persistent?

0   1   2   3   4   5   6   7   8   9   10   [   ]
No risk   *Very large risk*

8. In your estimation, what are the chances you will be working your normal duties (at home or work) in 3 months

0   1   2   3   4   5   6   7   8   9   10   (10-)[   ]
No chance   *Very Large Chance*

9. An increase in pain is an indication that I should stop what I'm doing until the pain decreases.

0   1   2   3   4   5   6   7   8   9   10   [   ]
Completely disagree   *Completely agree*

10. I should not do my normal work (at work or home duties) with my present pain.

0   1   2   3   4   5   6   7   8   9   10   [   ]
Completely disagree   *Completely agree*

SUM:_____

Linton SJ, Nicholas M and McDonald, S. (2011) Development of a short form of the Orebro Musculoskeletal Pain Screening Questionnaire. Spine; 136: 1891-1895

Appendix 5a: Standardised instructions for objective measures

Measure	Standardised instructions
Anthropometry	*I am going to measure your height and weight. I will ask you to stand comfortably with your back against this ruler to measure your height. I will ask you to stand on these digital scales to measure your weight.*
Bone mineral density (DXA)	*I am going to measure the density of the bones in your back and hip. I am going to use this scanner machine to do this. You have signed a consent form to indicate you have understood that the scan I am completing exposes you to a very small amount of radiation, roughly equivalent to 1/1000th of the background radiation you would normally receive in one year living in Perth. In a moment I will ask you to change into a gown. You must remove any metal objects from your body, including piercing. I will be completing three scans. Each scan will require you to lay on your back. Your legs and arms may be positioned slightly differently for each scan. I will be instructing you on this. I will be operating this computer as the scan is running to check that it is progressing correctly. Each scan will take approximately five minutes. You are not expected to feel any ill-effects or pain during the scan. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Body composition (DXA)	*I am going to measure your body composition using the same scanner machine. I will ask you to lay on your back with your arms tightly by your side and legs together. Once in position, the scanner arm will slowly pass over you from head to toe. It is important that remain still during the scan. The scan will take between 6 and 11 minutes to complete. If at any time you need to move please let me know and I will pause the scan. I will check the progress of the scan on this computer. You are not expected to feel any ill-effects or pain during the scan. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me*
Upper back extensor muscle endurance (isometric chest raise test)	*I am going to measure the endurance of the muscles in your upper back. I am going to ask you to complete a chest lift test to do this. In a moment I will ask you to lay on your stomach with this wedge cushion under your hips. I will ask you to have your belly button level with the edge of this cushion. The test will involve you lifting your chest and holding it up over the cushion. I will be timing how long you can hold this position. To ensure you stay in the correct position I will place a strap around your hips and legs. Your hands will be positioned at your temples. As soon as your chest touches the bed or you feel unable to continue holding the position, the timer will stop and the test will finish. You are not expected to feel any ill-effects or pain during the test. I will demonstrate the test now. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Bra fit (professional criteria)	*I am going to assess the bra you are wearing. I will be looking at particular aspects of your bra and assessing them against a checklist of points. Do you have any questions?*
Thoracic kyphosis (Flexicurve)	*I am going to measure the curvature of your back. I am going to use this flexible ruler to do this. This will be in contact with your skin during testing. I am going to ask you to stand whilst I take the measure. I would like you to resume your normal standing posture. I am going to press the ruler gently against your spine so that it resembles the shape of your back. I will then transfer this to paper by tracing its outline and I will use this to calculate the angle of your back. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Posture (photogrammetry)	*I am going to measure your posture in two positions. In a moment I will attach several photo-reflective markers to your upper body. These will show up brightly on the photographs. I will be taking two photographs of you from the side. For the first photo I will ask you to sit comfortably on the plinth with your feet either side of this mark on the floor. For the second photo I will ask you stand comfortably with your feet either side of the same mark on the floor. You are not expected to feel any ill-effects or pain during the test. If at any point during testing you feel unable to continue I would like you to tell me.*

Measure	Standardised instructions
Upper back mobility (photogrammetry)	*I am going to measure how much movement you have in your upper back. I will be using a photographic assessment technique to do this. In a moment I will attach several photo-reflective markers to your upper body. These will show up brightly on the photographs. I will be taking two photographs of you from the side. For the first photo I will ask you stand comfortably with your head facing forwards. Your arms will be elevated in front of you with your hands holding a pole/support. For the second photo I will ask you to raise your arms up fully with your hands clasped. I want you to reach up and back as far as possible. I may adjust your movement slightly to ensure the correct technique. You are not expected to feel any ill-effects or pain during the test. The pictures will be taken quickly so that you are not holding the positions for a long time. I will demonstrate the test now. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Breast ptosis and breast splay (tape measure)	*I am going to measure the position of your breasts I will be using a tape measure to do this. In a moment I will ask you to remove your upper body clothing and bra. I will then mark several reference points on your body. I will be taking two measures using the nipple as a reference point. I will ask you to sit with your hands on your hips whilst the measures are taken. You are not expected to feel any ill-effects or pain during the test. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Objective bra size (tape measure)	*I am going to measure your bra size using a tape measure. I will ask you to stand with your arms elevated as I position the tape measure around your chest. I will take two measurements. The first measure will be taken with the tape measure around your chest directly below the bust. The second measure will be taken with the tape measure across the fullest part of your breasts, roughly level with your nipples. I will ask you to exhale and hold a breath whilst the measures are taken. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*
Pressure pain thresholds of selected skeletal and muscular tissue in the upper back and torso (digital algometry)	*I am going to measure the pressure sensitivity of several points on your back and upper body. I am going to use this digital algometer to do this. This is the probe of the algometer that will be in contact with your skin during testing. I am going to initially mark 12 points on your back and upper body. I am going to press the algometer probe against these points in turn. Gradually the pressure of the probe against your skin will increase. As soon as the feeling of pressure becomes painful I want you to push this hand held switch. Once you push this switch the pressure will stop. The pressure reading will then be recorded. I am going to test each point three times. The order that I test them in will be randomly decided. I will now demonstrate the procedure using a point on your hand. Do you have any questions? If at any point during testing you feel unable to continue I would like you to tell me.*

Appendix 5b: Professional bra fitting criteria

356

Band	☐ Too tight: flesh bulging over top of band; subjective discomfort "feels too tight" ☐ Too loose: band lifts when arms are moved above head, posterior band not level with inframammary fold
Cup	☐ Too big: wrinkles in cup fabric ☐ Too small: breast tissue bulging above, below or at the sides
Underwire	☐ Incorrect shape: underwire sitting on breast tissue laterally (under armpit) or anterior midline; subjective complaint of discomfort
Straps	☐ Too tight: digging in; subjective complaint of discomfort; carrying too much of the weight of the breasts ☐ Too loose: sliding down off shoulder with no ability to adjust the length
Front band	☐ Not all in contact with the sternum
Rating of bra fit	☐ Pass: no errors or if hooks or straps can be adjusted to allow correct fit ☐ Fail: any other ticks

Appendix 6a: Attribution statements of co-authors

To Whom It May Concern I, Linda Spencer, contributed to the conceptualization, data curation, formal analysis and writing of the publication entitled Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods. Osteoporos Int. 2019. doi:10.1007/s00198-019-05023-5

.............███████████████████████......... (Signature of Candidate)

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Dr Robyn Fary   .....

Dr Leanda McKenna   .....

Dr Richard Ho   .....

Dr Kathy Briffa   .....

357
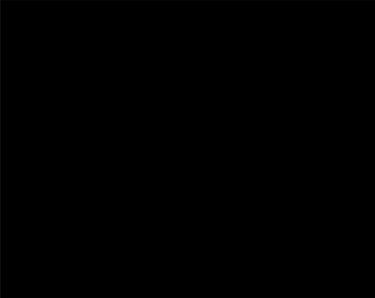
To Whom It May Concern, I, Linda Spencer, contributed to the conceptualisation, data curation, formal analysis and writing of the publication entitled: The relationship between breast size and aspects of health and psychological wellbeing in mature-aged women. Women's Health. 2020. doi: 10.1177/1745506520918335.

.... ███████████ ..:...... (Signature of Candidate)

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Dr Robyn Fary   ...... ████████████ ....
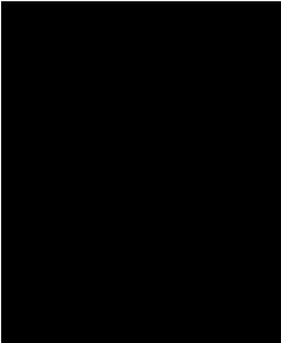
Dr Leanda McKenna   ...... ████████████ ....

Dr Jennifer Lalor   ...... ████████████ ....

Ms Angela Jacques   ...... ████████████ ....

Dr Kathy Briffa   ...... ████████████ ....

To Whom It May Concern I, Linda Spencer, contributed to the conceptualization, data curation, formal analysis and writing of the publication entitled Upper back pain in postmenopausal women and associated physical characteristics. Public Library of Science (PLOS:One) 2019; doi: 10.1371/journal.pone.0220452

……████████████████:….. (Signature of Candidate)

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Dr Robyn Fary   ……

Dr Leanda McKenna   ……

Ms Angela Jacques   ……

Dr Kathy Briffa   ……
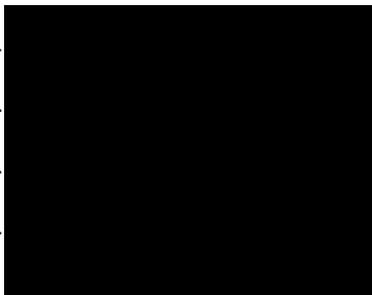
To Whom It May Concern, I, Linda Spencer, contributed to the conceptualization, data curation, formal analysis and writing of the publication entitles: Is breast size related to prevalent vertebral fracture? A cross-sectional study J Bone Miner Res Plus, 2020; doi: 10.1002/jbm4.10371.

.... █████████████████████ .... (Signature of Candidate)

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Dr Robyn Fary ....████████████████████..

Dr Leanda McKenna ....████████████████████..

Dr Richard Ho ....████████████████████..

Dr Kathy Briffa ....████████████████████..

360
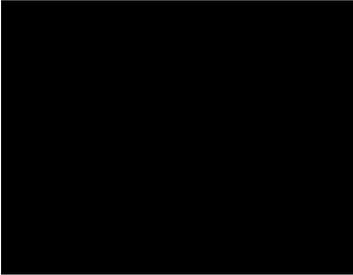
To Whom It May Concern, I, Linda Spencer, contributed to the conceptualization, data curation, formal analysis and writing of the publication entitled: Taking the strain: An examination of upper back musculoskeletal tissue sensitivity in relation to breast size and upper back pain. As submitted to The Clinical Journal of Pain, June 2020.

.... ████████████████ .... (Signature of Candidate)

I, as a Co-Author, endorse that this level of contribution by the candidate indicated above is appropriate.

Dr Robyn Fary   ......█████████████████████

Dr Leanda McKenna   ......█████████████████████

Ms Angela Jacques   ......█████████████████████

Dr Kathy Briffa   ......█████████████████████

Appendix 6b: Chapter 3 copyright permissions

PERMISSION TO USE COPYRIGHT MATERIAL AS SPECIFIED BELOW:

Digital algometer © Somedic

I hereby give permission for **Linda Spencer** to include the abovementioned material in her higher degree thesis for Curtin University, and to communicate this material via the espace institutional repository. This permission is granted on a non-exclusive basis and for an indefinite period.

I confirm that I am the copyright owner of the specified material.

Signed:
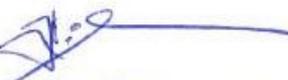
Name: Bo Johansson

Position: CEO, Somedic Senselab AB

Date: October 3, 2019

Please return signed form to **Linda Spencer, Linda.spencer@postgrad.curtin.edu.au.**

Appendix 6c: Chapter 5 Copyright permissions

Copyright Transfer Statement (CTS) for your article in Osteoporosis International (5023)

Springer <springerauthorquery@springeronline.com>

Tue 21/05/2019 2:07 PM

To: Linda Spencer <linda.spencer@curtin.edu.au>;
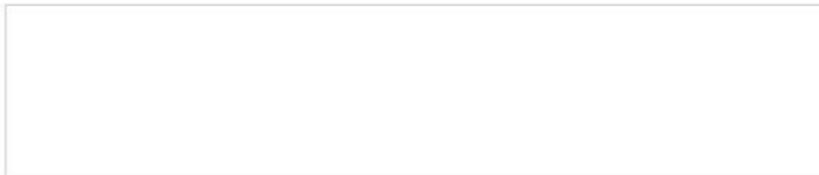
Copyright Transfer

21.05.2019

visit us at springer.com

Confirmation of your Copyright Transfer

Dear Author,

Please note: This e-mail is a confirmation of your copyright transfer and was sent to you only for your own records.

1. Publication
The copyright to this article, (including any supplementary information and graphic elements therein (e.g. illustrations, charts, moving images) (the 'Article'), is hereby assigned for good and valuable consideration to International Osteoporosis Foundation and National Osteoporosis Foundation (the 'Assignee'). Headings are for convenience only.

2. Grant of Rights
In consideration of the Assignee evaluating the Article for publication, the Author(s) grant the Assignee without limitation the exclusive (except as set out in clauses 3, 4 and 5 a) iv), assignable and sub-licensable right, unlimited in time and territory, to copy-edit, reproduce, publish, distribute, transmit, make available and store the Article, including abstracts thereof, in all forms of media of expression now known or developed in the future, including pre- and reprints, translations, photographic reproductions and extensions. Furthermore, to enable additional publishing services, such as promotion of the Article, the Author(s) grant the Assignee the right to use the Article (including the use of any graphic elements on a stand-alone basis) in whole or in part in electronic form, such as for display in databases or data networks (e.g. the Internet), or for print or download to stationary or portable devices. This includes interactive and multimedia use as well as posting the Article in full or in part or its abstract on social media, and the right to alter the Article to the extent necessary for such use. The Assignee may also let third parties share the Article in full or in part or its abstract on social media and may in this context sub-license the Article and its abstract to social media users. Author(s) grant to Assignee the right to re-license Article metadata without

363

restriction (including but not limited to author name, title, abstract, citation, references, keywords and any additional information as determined by Assignee).

3. Self-Archiving
Author(s) are permitted to self-archive a pre-print and an author's accepted manuscript version of their Article.

a. A pre-print is the author's version of the Article before peer-review has taken place ("Pre-Print"). Prior to acceptance for publication, Author(s) retain the right to make a Pre-Print of their Article available on any of the following: their own personal, self-maintained website; a legally compliant, non-commercial pre-print server such as but not limited to arXiv and bioRxiv. Once the Article has been published, the Author(s) should update the acknowledgement and provide a link to the definitive version on the publisher's website: "This is a pre-print of an article published in [insert journal title]. The final authenticated version is available online at: https://doi.org/[insert DOI]".

b. An Author's Accepted Manuscript (AAM) is the version accepted for publication in a journal following peer review but prior to copyediting and typesetting that can be made available under the following conditions:

   a. Author(s) retain the right to make an AAM of their Article available on their own personal, self-maintained website immediately on acceptance,
   b. Author(s) retain the right to make an AAM of their Article available for public release on any of the following 12 months after first publication ("Embargo Period"): their employer's internal website; their institutional and/or funder repositories. AAMs may also be deposited in such repositories immediately on acceptance, provided that they are not made publicly available until after the Embargo Period.

An acknowledgement in the following form should be included, together with a link to the published version on the publisher's website: "This is a post-peer-review, pre-copyedit version of an article published in [insert journal title]. The final authenticated version is available online at: http://dx.doi.org/[insert DOI]".

4. Authors' Retained Rights
Author(s) retain the following non-exclusive rights for the published version provided that, when reproducing the Article or extracts from it, the Author(s) acknowledge and reference first publication in the Journal:

a. to reuse graphic elements created by the Author(s) and contained in the Article, in presentations and other works created by them;

b. they and any academic institution where they work at the time may reproduce the Article for the purpose of course teaching (but not for inclusion in course pack material for onward sale by libraries and institutions); and

c. to reproduce, or to allow a third party Assignee to reproduce the Article in whole or in part in any printed volume (book or thesis) written by the Author(s).

5. Warranties
The Author(s) warrant and represent that:

a. (i) the Author(s) are the sole copyright owners or have been authorised by any additional copyright owner(s) to assign the rights defined in clause 2, (ii) the Article does not infringe any intellectual property rights (including without limitation copyright, database rights or trade mark rights) or other third party rights and no licence from or payments to a third party are required to publish the Article, (iii) the Article has not been previously published or licensed, (iv) if the Article contains material from other sources (e.g. illustrations, tables, text quotations), Author(s) have obtained written permissions to the extent necessary from the copyright holder(s), to license to the Assignee the same rights as set out in Clause 2 but on a non-exclusive basis and without the right to use any graphic elements on a stand-alone basis and have cited any such material correctly;

b. all of the facts contained in the Article are according to the current body of science true and accurate;

c. nothing in the Article is obscene, defamatory, violates any right of privacy or publicity, infringes any other human, personal or other rights of any person or entity or is otherwise unlawful and that informed consent to publish has been obtained for all research participants;

364

    d. nothing in the Article infringes any duty of confidentiality which any of the Author(s) might owe to anyone else or violates any contract, express or implied, of any of the Author(s). All of the institutions in which work recorded in the Article was created or carried out have authorised and approved such research and publication; and

    e. the signatory (the Author or the employer) who has signed this agreement has full right, power and authority to enter into this agreement on behalf of all of the Author(s).

6. Cooperation

The Author(s) shall cooperate fully with the Assignee in relation to any legal action that might arise from the publication of the Article, and the Author(s) shall give the Assignee access at reasonable times to any relevant accounts, documents and records within the power or control of the Author(s). The Author(s) agree that the distributing entity is intended to have the benefit of and shall have the right to enforce the terms of this agreement.

7. Author List

After signing, changes of authorship or the order of the authors listed will not be accepted unless formally approved in writing by the Assignee.

8. Edits & Corrections

The Author(s) agree(s) that the Assignee may retract the Article or publish a correction or other notice in relation to the Article if the Assignee considers in its reasonable opinion that such actions are appropriate from a legal, editorial or research integrity perspective.

This is an automated e-mail; please do not reply to this account. If you have any questions, please go to our help pages.

Thank you very much.

Kind regards,

Springer Author Services

Article Details

Journal title	Article title
Osteoporosis International	Thoracic kyphosis assessment in postmenopausal women: an examination of the Flexicurve method in comparison to radiological methods.
DOI	**Corresponding Author**
10.1007/s00198-019-05023-5	Linda Spencer
Copyright transferred to	**Transferred on**
International Osteoporosis Foundation and National Osteoporosis Foundation	Tue May 21 08:07:14 CEST 2019

Service Contacts

Springer Nature Customer Service Center

Tiergartenstr. 15-17
69121 Heidelberg
Germany
phone: +49 6221 345 0
fax: +49 6221 345 4229
customerservice@springernature.com

Springer New York, LCC

233 Spring Street
New York, NY 10013
USA
phone: +1 212 460 1500 or 800-SPRINGER
(Weekdays 8:30am - 5:30pm ET)
fax: +1 212-460-1700
customerservice@springernature.com

366