

School of Nursing, Midwifery and Paramedicine

Skin Tear Prediction in the Elderly: A Cohort Study

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Doctor of Philosophy

of

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Declarations

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.

Human Ethics The proposed research study 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 research proposal received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number RD-23-13.

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Date: *13th September 2017*

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Abstract

Introduction

Skin tears comprise a substantial portion of all wounds found amongst older adults with the majority of injuries occurring on the extremities. However, the relative importance and predictive significance of chronological, environmental and lifestyle factors have on age-related skin properties, clinical skin manifestations and the risk of skin tears is largely unquantified.

Objective

A 6-month prospective cohort study was conducted in a residential aged care population to investigate the feasibility and reliability of non-invasive technologies to objectively quantify morphological and physiological properties of ageing skin, and to examine baseline individual characteristics, skin characteristics, and morphological and physiological skin properties and the risk of skin tear incidents at 6-months.

Method

A sample of 200 aged care residents from four Western Australian facilities were assessed by a single investigator, with a broad range of individual and skin characteristics recorded. A range of non-invasive technologies including the DermaLab Combo®, Sebumeter®, Skin-pH-Meter® and skin blotting sampling were then used to objectively measure morphological and physiological skin properties. Except for skin blotting, where a single measurement was collected at the initial assessment, three consecutive measurements were taken for each skin property over five test sites (including the bilateral upper and lower extremities and the abdomen) and across two-time periods, 6-months apart.

Results

Having obtained good intrarater reliability for most skin properties over a single event measurement (three consecutive measurements) and over time (6-months apart), multivariable logistic regression modelling identified five variables that significantly predicted the risk of a skin tear. These variables included male

gender, a previous history of skin tears, a previous history of falls, and cutaneous manifestations of elastosis and purpura. The analysis did not identify any skin property that predicted the risk of skin tears at 6-months. Additional multivariable analysis however, showed some skin properties significantly predicted the risk of clinical manifestations of elastosis and purpura. Accordingly, three individual variables (age, gender, smoking), three clinical skin variables (uneven skin pigmentation, cutis rhomboidalis nuchae, history of actinic keratosis) and one skin property variable (collagen type IV) predicted the risk of skin elastosis. In contrast, four individual characteristics (age, history of skin tears, history of falls, antiplatelet therapy) and three skin properties (pH, subepidermal low echogenicity band of the forearms, skin thickness) predicted the risk of purpura.

Analysis using sensitivity and specificity, together with a receiver operator characteristic (ROC) curve, indicated the proposed skin tear model provided very good discrimination for correctly classifying participants with and without skin tears.

Conclusion

Non-invasive devices were found to be safe, practical, objective and reliable tools for quantifying ageing skin properties. Multivariable analysis developed a skin tear model with three individual and two skin characteristic variables that independently predicted the risk of skin tears at 6-months. The predictive model is simple to use, relevant to any health care setting and dispenses with the need to purchase expensive technologies that require specialised training. The two clinical manifestations (elastosis and purpura) which increased the risk of skin tears resulted from progressive changes to the structural and mechanical supporting proteins of skin, secondary to the chronological, environmental and lifestyle related risk factors. The study findings inform a new definition for skin tears.

List of Publications and Presentations Resulting from the Study

List of Publications

- Rayner, R., Carville, K., Leslie, G., & Dhaliwal, S. S. (2017). Measurement of morphological and physiological skin properties in aged care residents: A test–retest reliability pilot study. *International Wound Journal*, 14(2), 420-429. doi:10.1111/iwj.12621
- Rayner, R., Carville, K., Leslie, G., & Roberts, P. (2015). A review of patient and skin characteristics associated with skin tears. *Journal of Wound Care*, 24(9), 406-414. doi:10.12968/jowc.2015.24.9.406

List of Presentations

Oral

- Identification of factors associated with skin tears in aged care residents: A cohort study results. Western Australian Wound Management Association Advancement in Wound Management Study Day, Perth, 26 November, 2016.
- Identification of skin characteristics associated with skin tears in aged care residents: A cohort study results. Australian Wound Management Association National Conference, Melbourne Convention Centre, 9-12 November, 2016.
- Identification of individual characteristics associated with skin tears in aged care residents: A cohort study results. Australian Wound Management Association National Conference, Melbourne Convention Centre, 9-12 November, 2016.
- Morphological and physiological skin properties associated with skin tears in the elderly: A test-rest study. World Union of Wound Healing Societies. Florence, Italy, 26 September, 2016.
- Risk factors associated with skin tears in an aged care population: Results of a cohort study. The Mark Liveris Health Sciences Research Student Seminar. Curtin University, 1 September, 2016.

- Non-invasive technologies and the examination of individual and skin characteristics associated with skin tears in the elderly: A test-retest study. The Mark Liveris Health Sciences Research Student Seminar. Curtin University, 3 September, 2015.
- Identification of skin characteristics associated with skin tears in older Adults. Wound Management Innovation CRC, Brisbane, 9 March 2015.
- Results of a test-retest pilot study: Utility of non-invasive technologies to assess skin properties of aged care residents. School of Nursing and Midwifery Research Week. Curtin University, 27 November, 2014.
- Results of a test-retest pilot study: Utility of non-invasive technologies to assess skin properties of aged care residents. The Mark Liveris Health Sciences Research Student Seminar. Curtin University, 11 November, 2014.

Poster

- Exploration of the association between skin characteristics and skin tear formation in older adults. Australian Wound Management Association National Conference, Gold Coast Convention and Exhibition Centre, 7-10 May 2014.

List of Abbreviations

Abbreviation	Explanation
ABPI	Ankle brachial pressure index
COPD	Chronic obstructive pulmonary disease
CVA	Cerebral vascular accident
DEJ	Dermal-epidermal junction
ECM	Extracellular matrix
GAGs	Glycosaminoglycans
ICC	Intraclass correlation coefficient
ICD	International Classification of Diseases
LEAD	Lower extremity arterial disease
<i>M</i>	Mean
MHz	Megahertz
MPa	Megapascal
NMF	Natural moisturising factors
PPG	Photoplethysmography
QoL	Quality of life
RAT	Risk assessment tool
RH	Relative humidity
ROC	Receiver operating characteristic
SC	Stratum corneum
<i>SD</i>	Standard deviation
SLEB	Subepidermal low-echogenicity band
SPSS	Statistical Package for the Social Sciences
TEWL	Transepidermal water loss
TBPI	Toe brachial pressure index
UV	Ultraviolet
vs.	Versus

List of Symbols

Symbol	Explanation
α	Alpha
χ^2	Chi-square
J/m^2	Joule/square metre
kg/m^2	Kilogram/square metre
μg	Microgram
μm	Micrometre (1000 th of a millimetre)
μs	Microseconds
μS	Micro-siemens
%	Percentage(s)

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Glossary of Terms

Acanthotic

Hyperplasia or thickening of the epidermal layer of the skin.

Actinic keratosis

A focal skin lesion of hyper-proliferating keratinocytes that manifests on exposed skin surfaces from UV-induced damage to keratinocytes.

Activities of daily living

The distinct set of activities (movement in bed, transfers, locomotion, dressing, personal hygiene, and feeding) that are necessary for general self-caring.

Advanced glycation end products

The non-enzymatic reaction between free amino groups in proteins and a reducing sugar, which induces a complex series of reorganisation and dehydration that results in the formation of an irreversible cross-linked product.

Anisotropic behaviour

The physical property of skin to move in different directions.

Antiplatelet therapy

Medication that inhibits platelet aggregation.

Areolar tissue

Loose, irregularly arranged connective tissue that comprises of collagen fibres, elastic fibres, reticular fibres and glycosaminoglycans (GAGs).

Biophysical skin analysis

The scientific use of instruments to objectively quantify various skin characteristics including: morphological (colour, thickness, elasticity) and physiological (transepidermal water loss [TEWL], hydration, sebum and pH) properties. Biophysical skin analysis is also known as 'skin engineering'.

Body mass index

An estimate of an individual's adiposity based on their weight divided by the square of their height (kg/m^2).

Braden Scale

A tool used for predicting the risk of pressure injuries.

Bruising (contusion)

The localised extravasation of blood from capillaries or larger blood vessels in the skin or subcutaneous tissue from mechanical trauma such as a blunt or crush injury without loss of skin surface integrity. The extravasated blood results in visible skin discolouration that progressively dissolves over 2-3 weeks with the bruise undergoing the following characteristic colour changes that encompass: red, blue and purple in the first 5 days; green after 5-7 days; and yellow after 1-2 weeks.

Casual sebum level

The level of lipids that are present on the skin surface prior to conducting an assessment or being cleansed. It is a global term for evaluating skin greasiness and is generally recorded not less than 4 hours after the skin has been cleansed.

Chi-square tests

A non-parametric statistic test that is used to evaluate frequency data for categorical variables.

Chronological skin ageing

Skin changes that arise from the passage of time.

CIEL *a*b*

An abbreviation for the French *Commission Internationale de L'Eclairage* where colour values are reported in a three-dimensional space. The vertical L* axis of the colour space represents lightness. The a* and b* axis is at right angles to one another across the horizontal axis with: a* axis signifying green at the negative and red at the positive limit; and b* axis denoting blue on the negative and yellow on the positive axis.

Cognitive Performance Scale

A scale that is generally included in a geriatric assessment and is used to evaluate cognitive functioning as part of the individuals total functioning.

Cohen's effect size

A measure of the strength of association between values that is considered to have a practical significance.

Collagen type IV

A ubiquitous, dense, network-forming extracellular matrix protein that is synthesised in the skin by epidermal keratinocytes and dermal fibroblasts. It is the principle component of the dermal-epidermal junction and provides mechanical stability and structural support to the skin.

Confidence interval

An interval estimate, around a sample statistic that is intended to have a certain (generally 95%) probability of containing the true population value of that statistic.

Corneodesmosomes

An intercellular cytoskeleton structure that attaches corneocytes in the upper stratum corneum. Proteolytic degradation of the corneodesmosomes promotes desquamation.

Cutaneous manifestations of elastosis

Refers to the appearance of skin across photo-exposed sites that on touch has a firm, coarse, thickened, scaly, dry, and rigid texture compared to adjacent non-exposed skin sites. In severe cases, the skin displays a cobblestone or leathery appearance.

Cutis rhomboidalis nuchae

A cutaneous manifestation of the nape of the neck that is characterised by the appearance of cross-like deep furrows.

Dermatoporosis

The manifestation of fragile skin or cutaneous insufficiency that is associated with chronological ageing, chronic sun exposure, and the long-term use of corticosteroids.

Dermis

A contiguous, connective tissue construct that lies beneath the dermal-epidermal junction. It provides skin with mechanical support, oxygen and nutrition.

Dermal-epidermal junction

An irregular, undulating structure between the dermis and epidermis that significantly increases the surface area between the layers of the skin to permit the exchange of oxygen, nutrients, and waste products.

Distensibility

Refers to the elevation of skin under tensile stress. Distensibility is a surrogate measure of skin stiffness and reflects the ability of skin to stretch, which is primarily due to dermal collagen fibres.

Ecchymosis

A general term that refers to the extravasation of blood into the skin.

Ecchymotic lesions

Skin manifestations that are macular (flat), rounded or irregular lesions in shape with a bluish/purplish colour. Their circumference is larger than two millimetres in diameter.

Echogenicity

Used in ultrasonography to characterise the reflect ultrasonic waves back to a transducer. The intensity of tissue echogenicity is denoted by colour imaging which ranges from white for high echogenicity to black for no echogenicity.

Elasticity

The property of tissue to return to its natural state following extension or deformation. This property is primarily governed by elastic fibres.

Elastin

A protein found in connective tissue that has the capacity to resume its shape after extending or contracting.

Epidermis

The self-renewing outer skin layer that is comprised of stratified squamous keratinised epithelium, which is arranged in five distinct layers including the stratum corneum, stratum lucidum (found in the palms of hands and soles of feet), stratum granulosum, stratum spinosum and stratum basale.

Extracellular matrix (ECM)

A complex structure that comprises of macromolecules of protein and carbohydrate in which cells are embedded.

Extrinsic ageing

The cumulative impact of external influences such as exposure environmental and lifestyle-related factors on normal skin ageing processes.

Fitzpatrick Skin Type Classification

Tool used to grade an individual's propensity to tan following sun exposure. Initially developed to predict skin reactivity to photochemotherapy.

Fragile skin

Skin with reduced resistance to physical forces.

Haematomas

The collection of physically palpable blood that forms in the skin or subcutaneous tissue. It may present as a superficial collection of blood such as beneath the flap of a skin tear or a deeper soft tissue haematoma, which can cause extensive tissue destruction and necrosis.

Hydration

A general term referring to the water content of the stratum corneum.

Hypoechoic

Used in ultrasonography to characterise tissue that does not effectively reflect ultrasonic waves back to a transducer.

Hypodermis

The layer of loose connective tissue that lies beneath the dermis of the skin.

Incidence studies

Studies that measure the number of new cases of a condition over a specified period of time.

Integumentary

Skin and its associated structures such as sebaceous glands, sweat glands, hair and nails.

Intraclass correlation coefficient

An inferential statistical measure that is used to determine the reliability of measurements.

Intrarater reliability

The ability of a rater to reproduce the same results under similar, repeated measurement conditions.

Intrinsic ageing

The natural ageing processes.

In vitro

Refers to biological studies undertaken in the laboratory.

In vivo

Refers to biological studies conducted in a living model.

Keratinocytes

Specialised epithelial cells that synthesise structural components of the epidermis through differentiation.

Lentigines

Benign hyperpigmented, irregular, flat spots located on chronically sun exposed areas of the body.

Logistic regression

A statistical method, which constructs a statistical model that describes the relationship between dichotomous outcomes and an array of independent predictor or explanatory variables.

Manifestation

Visual clinical signs of skin changes.

Matrix metalloproteinases (MMPs)

Proteinases that have the ability to degrade the extracellular matrix.

Mean

Indicates the central point of a distribution.

Multivariable analysis

A statistical procedure that simultaneously explores multiple independent variables to determine if they are associated with the dependent variable.

Oedema

The accumulation of fluid into interstitial spaces. Oedema can be classified as localised or generalised.

Odds ratio

A statistic technique commonly used in cohort studies to measure the strength of association between a risk and an outcome. It determines the odds that a risk will arise from a specific exposure compared to the odds of the risk not arising when the exposure is absent.

Pearson's product-moment correlation coefficient

A statistical measure to determine the strength of linear relationship between two variables.

Photoageing

Changes to the skin that are induced from exposure to ultraviolet (UV) radiation. The cumulative impact of these changes is superimposed on chronologically aged skin.

Plasticity

The property of cells to change shape following deformation, which is dependent on the stratum corneum level of hydration.

Post-translational modification

Modifications of proteins during or following protein synthesis.

Prevalence studies

A study of the number of individuals in a population with a particular condition at a given point in time.

Prospective cohort study

A study that follows a group of individuals of interest (cohort) over a designated period of time.

Pseudoscars

Pseudoscars are whitish, irregular shaped scars that spontaneously occur on photo-exposed skin sites, without a previous break to the skin surface. They are commonly seen in association with purpura.

Purpura

Non-inflammatory ecchymotic lesions of the skin that range in diameter between 2–20mm.

Receiver operator characteristic (ROC)

A graphical means of evaluating the ability of a test to discriminate between individuals with and without a condition. The size of the area under the curve determines this ability.

Retraction

Refers to the ability of skin to recover from a stress.

Sebum

Refers to the oily substance that is secreted by the sebaceous gland and spreads across the skin surface.

Senile purpura

Senile purpura is a non-inflammatory ecchymotic skin lesion that varies in size and can manifest as extensive ecchymotic lesions. These lesions may also be referred to as actinic purpura, Bateman's purpura, traumatic purpura or corticosteroid purpura. For the purpose of this study senile purpuric lesions were defined as an extensive ecchymosis skin lesion that was greater than 20mm.

Sensitivity

The portion of positive cases that are correctly predicted by a statistical model.

Shearing

The stress that arises when applied forces result in two contiguous surfaces deforming along a transverse plane.

Skin blotting

A technique to measure the transepidermal secreted skin proteins type IV collagen, matrix metalloproteinase-2, and tumour necrosis factor- α .

Skin structural intensity score

A calculation of the average value of the density of dermal collagen (an echogenic protein marker synthesised by fibroblasts).

Skin pH

A measure of the level of acidity or alkalinity of the surface of the skin.

Skin thickness

Refers to the whole thickness of the skin and combines the depth of both the epidermis and the dermis.

Skin tears

A traumatic wound that generally occurs on the extremities of older adults. It occurs when the epidermis detaches from the dermis or where the epidermis and dermis separate from underlying structures.

Smallest detectable change

Refers to the smallest change in a score, which can be detected with a device, above the measurement error.

Specificity

The portion of negative cases that are correctly predicted by a statistical model.

Standard deviation

A measure of the dispersion of a set of values from the mean.

STAR Skin Tear Classification

A skin tear classification system devised in Australia.

Stiffness

The ability of skin to resist deformation.

Subepidermal low echogenicity band (SLEB)

A hypoechoic band due to ageing that is visible with ultrasound in the papillary dermis of the skin and which is exacerbated by exposure to ultraviolet radiation and photoageing.

***t*-test**

A statistical test to identify whether the mean of two groups are statistically different from each other at a specific level of significance.

Tensile strength

The degree to which skin can extend without tearing.

Test-retest intrarater reliability

Describes the reliability and stability of measurements by a device through the examination of similarity between observations undertaken by the same investigator on two separate occasions.

Toe brachial index (TBI)

A non-invasive measurement for determining arterial perfusion to the feet. The TBI is suitable for assessing vascular disease in individuals with diabetes and/or renal disease as digital vessels are rarely calcified.

Transepidermal water loss (TEWL)

The TEWL is the loss of water vapour or insensible perspiration from the surface of the skin (without sweat) and is commonly used to evaluate the permeability of skin.

Venous photoplethysmography (PPG)

A device used to screen for superficial and deep venous reflux by measuring the venous refilling time.

Viscoelasticity

The property of skin that exhibits both elastic and viscous characteristics when undergoing deformation. This skin property relates to the delay in recovery following deformation from the sliding of fibrous networks.

Wilcoxon signed-rank test

A non-parametric test for comparing two related samples.

Chapter 1

Introduction

Skin tears comprise a substantial proportion of all wounds found amongst older adults (Carville et al., 2007; Everett & Powell, 1994; Malone, Rozario, Gavinski, & Goodwin, 1991; Ratliff & Fletcher, 2007; White, Karam, & Cowell, 1994). Epidemiological data on prevalence of skin tears in long-term aged care facilities indicate they occur in 41–59% of Australians, 14–22% of North Americans and 4–14% of Japanese residents (Carville, Leslie, Osseiran-Moisson, Newall, & Lewin, 2014; Everett & Powell, 1994; Koyano, Nakagami, Iizaka, Sugama, & Sanada, 2017; LeBlanc, Christensen, Cook, Culhane, & Gutierrez, 2013; Sanada, Nakagami, Koyano, Iizaka, & Sugama, 2015; White et al., 1994). While the incidence of skin tears in long-term aged care facilities is poorly reported, rates of 5.76 and 10.57 per 1000 occupied bed days have been recorded in Australia, 1.13 per 1000 person-days in Japan, 3.5% cumulative incidence in Japan, and 0.92 per patient per year in North America (Carville et al., 2014; Koyano et al., 2017; Malone et al., 1991; Sanada et al., 2015). Regardless of the geographical location of these studies, skin tears primarily occurred on the upper extremities followed by the lower extremities of older individuals (Koyano et al., 2014; LeBlanc et al., 2013; Malone et al., 1991; Payne & Martin, 1990).

Increased longevity and the unprecedented ageing of the Australian population indicates that skin tears will be a growing problem amongst aged care residents (Edwards, Finlayson, Parker, Jensen, & Finlayson, 2015). Compared to other acute wounds, skin tears have generally been regarded as a relatively insignificant condition that are typically confined to the extremities of older individuals (LeBlanc, Christensen, Orsted, & Keast, 2008). Nevertheless, skin tears are a notable condition that have the potential to be painful, form chronic ulcerative wounds when located on the lower extremities, increase the risk of infection, reduce a person's quality of life (QoL), extend the length of hospital stays, and increase healthcare costs

(Groom, Shannon, Chakravarthy, & Fleck, 2010; LeBlanc et al., 2008; Lopez et al., 2011; Manning & Chrisakis, 2011).

The current clinical practice for identifying individual's at risk of skin tears appears to be based on a subjective appraisal of a broad range of individual and skin characteristics (Stephen-Haynes & Carville, 2011). These characteristics encompass: reviewing the individuals general health, mobility, age, skin fragility status, and previous history of skin tears (LeBlanc & Baranoski, 2014). To date, risk assessments of skin tears have not routinely incorporated non-invasive technologies to objectively quantify morphological and physiological skin properties. Moreover, the influence that age, gender, skin type; environmental exposure to ultraviolet (UV) radiation, residing geographical location, and lifestyle-related (smoking, nutrition, alcohol, stress, exercise, medications) factors have on ageing skin have not been extensively explored in relation to the risk of skin tears.

Moreover, in spite of the considerable advances over the last 30 years in the biophysical analysis of skin and the commercial availability of bioengineering technologies, only two studies in English-language publications reported using non-invasive technologies to quantify morphological or physiological skin properties associated with skin tears (Koyano et al., 2014; Koyano et al., 2017). Both of these studies were conducted in long-term medical facilities in Japan, where the reported incidents of skin tears are considerably lower than in Australia.

1.1. Background

In Australia, demographic data for 2012 indicates that individuals aged over 65 years and 85 years respectively accounted for 14.2% and 1.9% of the population (Australian Bureau of Statistics, 2012). It is projected that by 2040, the proportion of Australians aged over 65 years will make up 20% of the population, with the number of individuals aged 85 years and over accounting for 4% of the population (Australian Bureau of Statistics, 2013). The longevity of human life and concomitant increase in the proportion of older individuals with aged-related skin changes will potentially equate to

increased numbers of skin tears, and place a greater demand on scarce health resources.

The greater awareness over the past three decades around issues relating to ageing skin has seen a rise in the number of articles published that describe the assessment, prevention and management of skin tears (Baranoski, 2003; Bianchi, 2012; Camp-Sorrell, 1991; Holmes, Davidson, Thompson, & Kelechi, 2013; Lloyd-Jones, 2011; Ratliff & Fletcher, 2007; White et al., 1994; Xu, Lau, Taira, & Singer, 2009). Similarly, an increasing number of skin tear prevalence and incidents studies have been conducted across a broad range of health settings including residential care facilities, community and acute hospitals in Australia, Asia, North America, Latin America, and the United Kingdom (Amaral, Pulido, & Santos, 2012; Bank & Nix, 2006; Carville & Lewin, 1998; Chang, Carville, & Tay, 2016; Everett & Powell, 1994; Koyano et al., 2014; LeBlanc et al., 2013; Mulligan, Prentice, & Scott, 2011; Payne & Martin, 1990; Sanada et al., 2015).

Such studies have drawn attention to these previously under-reported wounds, and prompted the development of guidelines and consensus statements for their prevention and management (All Wales Tissue Viability Nurse Forum, 2011; LeBlanc & Baranoski, 2011; LeBlanc et al., 2008; National Guideline Clearinghouse, 2008). These documents however, have been based more on experiential and anecdotal evidence rather than empirical evidence. Further research is therefore needed to objectively quantify ageing skin characteristics and properties and identify factors that contribute to the risk of skin tears. Such knowledge will permit early identification of 'at-risk' individuals and the implementation of targeted preventative interventions that will ultimately improve the QoL of older adults, and reduce the cost of care for health providers.

1.2. Purpose of this Study

The purpose of this study was to investigate the utility of non-invasive technologies for measuring skin morphological and physiological skin properties in a residential aged care population and to develop a model to

predict the risk of skin tears using individual characteristics, skin characteristics, and skin properties.

1.3. Objectives of the Study

The objectives of this study were twofold:

1. To examine the feasibility and reliability of non-invasive technologies including the DermaLab Combo®, Sebumeter®, Skin-pH-Meter® and skin blotting sampling to objectively quantify morphological (colour, thickness, elasticity) and physiological (TEWL, hydration, pH, sebum, transepidermal skin proteins) properties of ageing skin; and
2. To develop a prediction model using baseline individual characteristics, skin characteristics, and morphological and physiological skin properties to predict incidents of skin tears in aged persons.

1.4. Significance of the Study

This prospective study contributes to a greater understanding of aged-related skin changes and the identification of factors that contribute to the risk of developing skin tears. The study has generated empirical evidence of skin tear risk, by clarifying clinical manifestation terminology, objectively quantifying skin properties, and identifying the influence that aged-related skin changes have on their development. This is the first Australian prospective study to objectively quantify the relationship between skin properties and skin tears and examine both individual characteristics and skin characteristics associated with their occurrence. Previous approaches for determining skin tear risk have primarily been reliant on anecdotal evidence, expert opinion and clinical observations, which may result in under-prediction or over-prediction of risk factors.

The findings will improve clinicians' knowledge for identifying older individuals at risk of skin tears. The early identification of older individuals at risk of skin tears will have significant benefits for timely and targeted implementation of preventive strategies, optimisation of QoL and reduced health expenditure. Furthermore, it is anticipated that the findings of the study

will inform health providers to establish quality performance indicators for the identification, prevention and benchmarking of skin tear incidents in residential care facilities.

1.5. Overview of the Thesis

The thesis is presented in nine chapters:

Chapter One (this chapter) introduces the research topic and provides the background, purpose, objectives, and significance of the study.

Chapter Two reviews and critiques publications regarding the empirical evidence around skin tear occurrence and associated risk factors. The chapter describes the skin architecture, influence of intrinsic and extrinsic skin ageing, skin tear definition and introduces the terminology cited in the later chapters, before examining the reported efficacy and safety of using non-invasive technologies to measure the properties of ageing skin. For the convenience of the reader images of clinical manifestations associated with intrinsic and extrinsic ageing have been included in the literature review.

Chapter Three outlines the study framework and rationale for undertaking a three-stage approach (preparatory stage, pilot study, and major study). The preparatory stage is described in detail along with the ethical considerations, study population, devices, data collection tools, and measurement issues.

Chapters Four and Five address the first research objective. Chapter Four describes the pilot and major studies that were conducted to establish the reliability of the non-invasive technologies used to measure ageing skin properties. The methodology, recruitment and eligibility criteria, study population, data collection, statistical methods and data analysis are described. The results of both the pilot and major study are then presented to provide a consolidated basis for the subsequent discussion in chapter Five. This structure avoids unnecessary repetition in the description of techniques

and methodology, as both the pilot and major study applied the same approach.

Chapter Five discusses the intrarater reliability findings of the pilot and major studies, and evaluates the utility of the range of technologies that were used in the research. This chapter informs the final selection of devices and skin properties that could be reliably measured and hence used in the modelling explored in the subsequent chapters.

Chapters Six and Seven address the second research objective. Chapter Six explores the effect of baseline individual characteristics, skin characteristics, and morphological and physiological skin properties on the incidents of skin tears at 6-months. The statistical methodology used to examine the influence of skin characteristics and properties is different to those adopted for the first research objective (described in chapter Four), so for clarity this chapter separately describes datasets and sequential statistical analyses. This is followed by a detailed presentation of the results for the various factors and variables.

Chapter Seven discusses the results and hence those baseline individual characteristics, skin characteristics, and morphological and physiological skin properties that best predicted the incidents of skin tears at 6-months. The discussion includes a broader comparison of the results from this study with evidence available in the literature.

Chapter Eight provides further discussion on the implications of the results by drawing together the findings from the study and the literature on changes to the structural integrity and mechanical properties of ageing skin, and interprets these findings in relation to skin tears. The discussion focuses on the epidermal, dermal-epidermal junction (DEJ), and dermal layers of the skin.

Chapter Nine presents the conclusion of the study in terms of the two key research objectives. The strengths and limitation of this study are discussed in relation to the key research objectives. Lastly, the chapter provides recommendations in terms of improving clinical practice and potential future research opportunities that emerged from the study findings.

Chapter 2

Literature Review

2.1. Introduction

This chapter provides an overview of the current evidence on individual characteristics, clinical skin characteristics and morphological and physiological skin properties that are reported to be associated with skin tears in older individuals. The influence of ageing is examined with respect to skin changes and a review of the use of non-invasive technologies for assessing skin properties is provided. The findings from this literature review was summarised and published in the following peer-reviewed journal article: Rayner, R., Carville, K., Leslie, G., & Roberts, P. (2015). A review of patient and skin characteristics associated with skin tears. *Journal of Wound Care*, 24(9), 406-414. Copyright permission to reprint this article is provided in Appendix A.

2.2. Overview of Literature Search Strategies

A detailed review of the published literature was initially conducted to identify all articles published between January 1980 and December 2013 using the following electronic databases: PubMed, Medline, CINAHL, Embase, Scopus, Evidence Based and Medicine Reviews (EBM). Key search terms related to skin tears included: 'aged', 'skin', 'tears or lacerations', 'skin tearing', 'geri tear', 'epidermal tear', 'prevalence', 'incidence' and 'incidents'. The words 'skin tear' was not conjointly used as it is not recognised as a National Library of Medical Subject Heading (MeSH) term because it is not indexed for Medline citation (National Library of Medicine, 2013). A repeat search of the same databases from between January 2014 and February 2017 identified an additional six articles of interest.

Inclusion criteria were English language, primary studies that identified individual and/or skin characteristics. Exclusion criteria included studies which related to special populations (such as obstetrics, gynaecology,

paediatrics, ocular), or those with Dupuytren's contractures (as these tear injuries may be indicators of different pathology). Skin tears associated with these special populations differed in their location and development from those that principally occur on the extremities of older individuals. Clinical practice guideline websites and reference lists of key articles were also searched for further resources.

The search criteria identified a total of 343 papers; 63 papers were excluded to remove duplicates and 271 were excluded following abstract review as they failed to address the inclusion criteria. A total of eight articles and one unpublished study (which was presented at a wound conference — Newall, Lewin, Carville, Santamaria, and Roberts (2010)), which described direct assessment of patient and/or skin characteristics in association with skin tears were included for the initial review. Figure 2.1 summarises the process and results of this literature search.

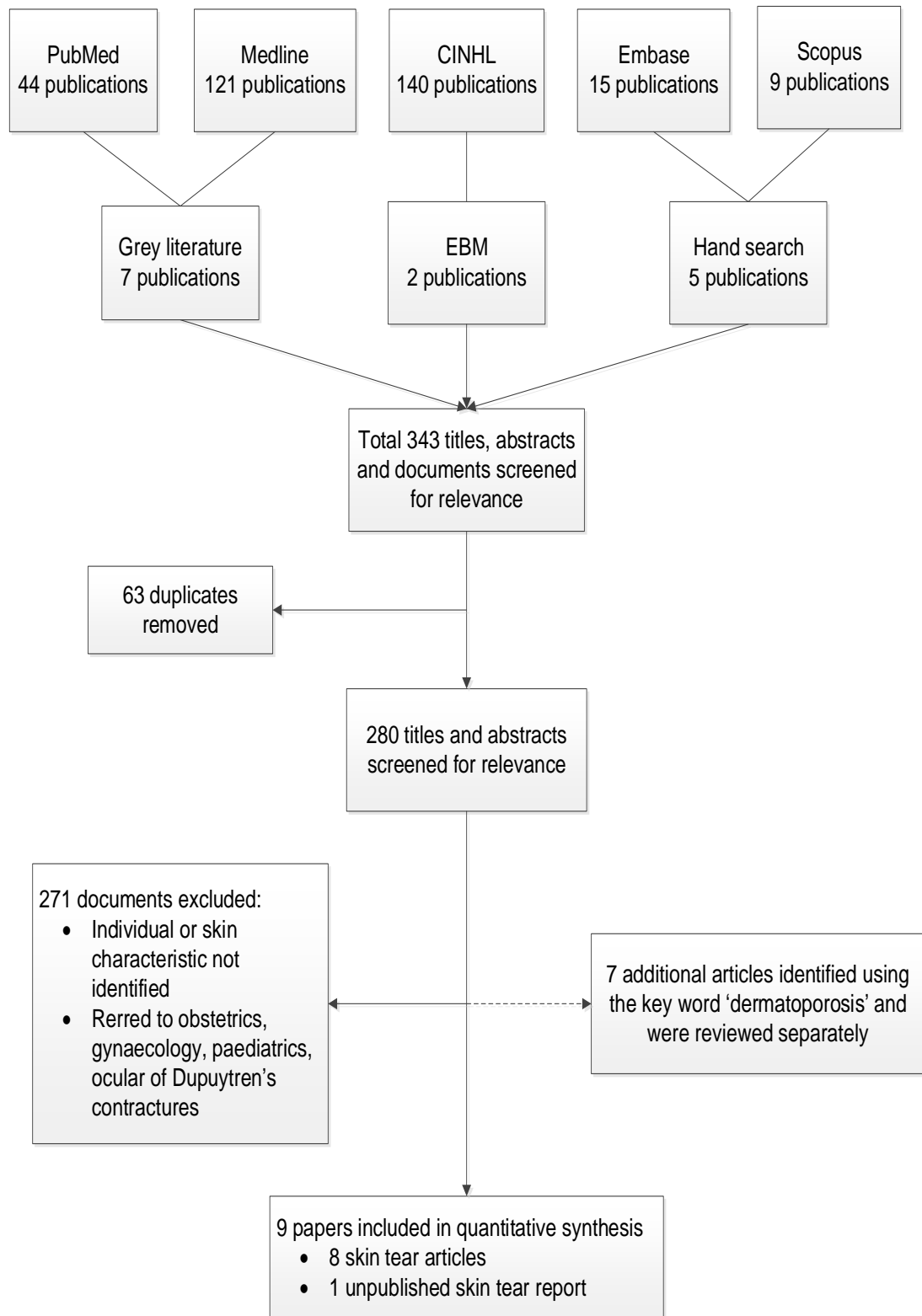


Figure 2.1. Flowchart of the skin tear literature review process between January 1980 and December 2013.

2.3. Skin Anatomy

Skin is the largest and most dynamic organ of the human body that both reacts to and physiologically reflects the influences of the exposed environment (Nemoto, Kubota, Murasawa, & Isogai, 2012). The basic structure of human skin is comprised of three layers vis-à-vis epidermis, dermis and hypodermis. The outer most layer of the skin, the epidermis, is a stratified layer of epithelial cells that forms a physical and dynamic barrier to separate the internal anatomical environment from the external milieu (Brandner et al., 2015). The epidermis affords mechanical resistance to applied forces and constitutes the principal barrier against invasion of micro-organisms or the detrimental effects of the environment (Diegel, Danilenko, & Wojcinski, 2013). The epidermal layer of the skin interfaces via the dermal-epidermal junction (DEJ) with the underlying dermal layer (McGrath & McLean, 2008).

The DEJ comprises of an upper lamina lucida and an inferior lamina densa layer (Zaidi & Lanigan, 2010). The lamina lucida, which lies at the base of the epidermis, contains anchoring filaments that attaches the epidermis to the lamina lucida, whereby additional anchoring fibrils extend from the lamina densa into the upper papillary layer of the dermis (Selby, 2011). The lamina densa is principally composed of type IV collagen that provide structural integrity by anchoring the dermis to the epidermis (Halfter et al., 2015). The DEJ is an irregular undulating structure that significantly increases the surface area between the dermis and the avascular epidermis to permit the exchange of oxygen, nutrients, and waste products (Adegbenro & Taylor, 2013).

The dermis is composed of sub-epithelial dense connective tissue that consists of a superficial papillary layer and a deeper reticular layer which governs the skin's mechanical behaviour (Moronkeji & Akhtar, 2015). The papillary dermis forms rete ridges or finger-like projections with the lamina densa to support the attachment of the dermis to the epidermis (Chilcott, 2008). The papillary dermis is comprised of loose connective tissue and a

horizontal plane of blood vessels referred to as the subpapillary plexus (Eckes, Krieg, & Niessen, 2010). The subpapillary plexus, which supplies blood to the upper dermis and specialised adnexa structures, forms a boundary between the papillary and reticular dermis and connects to a deep plexus situated in the hypodermis.

Structurally, the dermis consists of an extracellular matrix (ECM) that comprises of fibrous proteins known as collagen and elastin, which are embedded in a gel-like substance called glycosaminoglycans (GAGs) (Barcellos-Hoff, 2013). The ECM resists compressive forces while permitting diffusion of nutrients and metabolites (Cox & Erler, 2011). Collagen consists of well-regulated intra- and inter-molecular cross-links that provides the dermis with structural and mechanical supporting properties (Avery & Bailey, 2008; Fisher, Varani, & Voorhees, 2008). Based on per weight calculations, these cross-links provide collagen fibres with a tensile strength that resembles steel (Beckman, Shields, & Diegelmann, 2008). In contrast, elastic fibres endow skin with elasticity and resilience properties that permit skin to retract following deformation (Yang et al., 2015). The ECM governs the viscoelasticity (VE) behaviour of skin by permitting it to deform under stress and then resume its normal shape (Everett & Sommers, 2012; Silver, Freeman, & DeVore, 2001).

The hypodermis lies beneath but integrates with the dermis (Adegbenro & Taylor, 2013). The subcutaneous layer is composed of: white adipose tissue that contributes to regulating energy balance, vascular homeostasis and improves insulin sensitivity; and brown adipose tissue, which produces heat by dissipating energy (Peirce, Pellegrinelli, & Vidal-Puig, 2016). Specialised adnexa structures comprising of sebaceous glands, sweat glands, hair follicles and an intricate network of nerve fibres are interspersed throughout the layers of the skin (Robinson, 2014).

Human skin is susceptible to an array of influences including age, gender, genetics, skin type, environmental (exposure to UV radiation, pollutants, gravity, geographical location) and lifestyle (smoking, nutrition,

alcohol, stress, exercise, medications) related factors (Flament et al., 2013; Miyamae, Kawabata, Yamakawa, & Ozaki, 2013). The influence of these intrinsic and extrinsic factors on the skin manifests in a diverse array of clinical lesions, which become more evident as individuals age (Bosch et al., 2015). Cutaneous manifestations associated with intrinsic ageing include: fine wrinkles and laxity or slackness of the skin from loss of elasticity (Farage, Miller, Elsner, & Maibach, 2008; Waaijer et al., 2011; Yaar, 2006). Manifestations associated with extrinsic ageing consist of elastosis, uneven skin pigmentation, telangiectasia, actinic purpura, lentigines, cutis rhomboidalis nuchae, actinic keratosis (AK), and yellowing (Friedman, Lim, & Wang, 2016; Norman & Young Jr, 2014; Rittié & Fisher, 2015; Yu & Baron, 2013). Extrinsic factors have demonstrated to have a more pronounced impact on the skin than intrinsic factors as they are cumulative and superimpose on normal chronological or natural ageing processes (Vierkötter & Krutmann, 2012).

2.4. Defining Skin Tears

For the purpose of clearly illustrating aged-related skin tears two images are provided for the readers convenience in Figure 2.2. Permission to reproduce these wound images is provided in Appendix B. Despite the increasing interest in skin tears and the total number of relevant published articles, there was found to be no clear consensus on a definition (Cuzzell, 1990; Everett & Powell, 1994; LeBlanc & Baranoski, 2011; Malone et al., 1991; Payne & Martin, 1990; White et al., 1994; Yaar & Gilchrest, 2001). Moreover, the term 'skin tear' is not universally adopted throughout the literature. While 'skin tear' is the most commonly cited term used within the English literature, the terms 'skin tearing', 'skin laceration', 'geri tear', and 'epidermal tear' have been used to describe similar wounds (Cuzzell, 1986; Gottlieb & Penneys, 1980; Kennedy & Kerse, 2011; Yaar & Gilchrest, 2001).

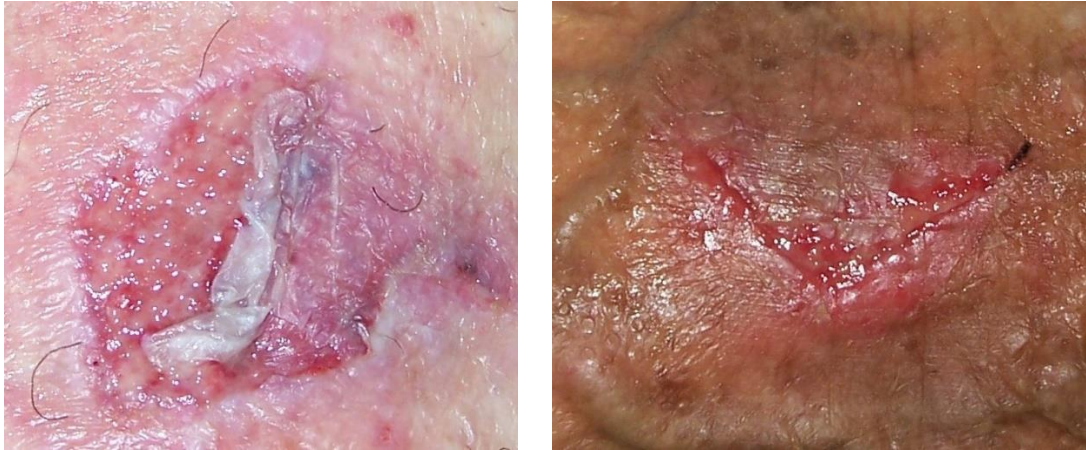


Figure 2.2. Skin tears recorded on dorsal forearms. Length of skin tears is approximately 25 mm in each image. (Reproduced with permission from Silver Chain).

The most widely cited definition is that of Payne and Martin (1993) (Becker, 2003; Gray, Stringfellow, & Cooper, 2011; Holmes et al., 2013; Lloyd-Jones, 2011). The authors however, did not outline the derivation process for their definition but defined a skin tear as:

A traumatic wound occurring principally on the extremities of older adults, as a result of friction alone or shearing and friction forces which separate the epidermis from the dermis (partial-thickness wound) or which separates both the epidermis and the dermis from underlying structures (full-thickness wound) (Payne & Martin, 1993 p. 22).

In 2011, a group of 14 registered nurses who referred to themselves as the International Skin Tear Consensus Panel reviewed this definition. They conducted a three-phase modified Delphi methodology to gain consensus on an updated definition for skin tears. The panel defined a skin tear as:

A wound caused by shear, friction, and/or blunt force resulting in separation of skin layers [that] can be partial-thickness (separation of the epidermis from the dermis) or full thickness (separation of both the epidermis and dermis from underlying structures (LeBlanc & Baranoski, 2011, p 6).

A perceived lack of international consensus on a definition may explain the absence of a specific category for coding skin tears in the World Health Organisation International Classification of Diseases (ICD) 10th edition (Australian Consortium for Classification Development, 2013). Under the ICD-10 coding 'skin tears' are generally coded as a superficial injury and labelled according to their anatomical site of injury. The absence of a specific code for skin tears may in part explain their perceived insignificance and potential for under-reporting of these wounds by health care professionals and agencies.

2.5. Skin Tear Research

A range of methodologies have been used to identify individual and/or skin characteristics associated with skin tears. These have included prevalence studies (Amaral et al., 2012; LeBlanc et al., 2013; Lopez et al., 2011), descriptive studies (McGough-Csarny & Kopac, 1998; Payne & Martin, 1990), and incidence reports (Everett & Powell, 1994; Malone et al., 1991; White et al., 1994).

Skin tear prevalence studies can be a valuable means of determining individual and skin characteristics when they are associated with comprehensive skin inspections and quantitative findings are reported. Prevalence surveys determine the proportion of a population with a particular disease or illness at a specific point in time (Parkin & Bray, 2005). In contrast, incidence rates measure how frequently an event occurs in a given population (Parkin & Bray, 2005). Incidence registers may, or may not, be designed to simultaneously record individual and skin characteristics associated with the injury and the robustness of incidence data is very much dependent on the accuracy and integrity of the reporting processes. The perception that skin tears are insignificant wounds as opposed to other trauma-related skin injuries may limit reporting, regardless of the type of methodology used.

The search of the literature between January 1980 and February 2017 identified 14 primary articles that identified individual and skin characteristics.

A list of all primary articles identifying individual and skin characteristics is presented in Table 2.1. The articles are listed in alphabetical order according to the first author.

Table 2.1. Individual and Skin Characteristics Associated with Skin Tears Identified from the Literature

Author and year	Sample size	Individuals with skin tears	Demographic details of persons with skin tears	Location of skin tears	Identified individual characteristics	Identified skin characteristics
Amaral et al. 2012	157	5 (9 skin tears)	Age ≤ 50 to > 70 years Males 2 (40.0) Females 3 (60.0)	Not reported	Low Braden Scale score 3 (60.0) Low Karnofsky score 5 (100.0) Less collaborative behaviour 3 (60.0)	Not reported
Everett & Powell, 1994	347	Mean 22 / month Total skin tears 133	Age of total survey population ranged from 40-94 years Mean age 80 years	Head (4.0) Arms (37.0) Legs (58.0)	Low dependency or dementia (43.0) Receiving analgesia (45.0) Poor balance (50.0) Normal mental status (29.0)	Fragile skin (79)
Koyano et al. 2014	412	16	92.5 (IQR 84.0-94.5) Males 4 (25.0) Females 12 (75.0)	Dorsal forearms (50.1)	No significant difference identified between patients with and without skin tears	Nil reported Skin properties Increased low-echogenic pixels Decreased type IV collagen and matrix metalloproteinase-2 Increased tumour necrosis factor-α (TNF-α)
Koyano et al. 2017	149	21 (52 skin tears)	Age > 65 years	Posterior forearm (34.6) Dorsal hand and fingers (19.2) Anterior lower leg (19.2)	142 patients only Males 8 (50.0) Females 8 (50.0) History of skin tears 10 (62.5) Steroid use	Nil reported Skin property Decreased dermal thickness

LeBlanc et al. 2013	113	25	Age of total survey population ranged from 36-107 years Gender of population with skin tears Males (38.7) Females (16.0)	Arms 15 (60.0) Legs 10 (40.0)	Possible history of skin tears Stiffness and spasticity Cognitive Performance Scale (RAI-MDS) score of 3 and 4 ADL (RAI-MDS) score of 4	Nil identified
Lewin et al. 2016	453	151	Mean age 80 years	Arms Legs Trunk Head	Chronic obstructive pulmonary disease Dementia Cognitively impaired Diabetic complications Malignant lymphoma Myocardial infarction Vascular disease Unable to reposition	Wrinkled loose skin Dry skin Healed skin tear Senile purpura Ecchymosis Haematoma Paper-thin skin Bulla Oedema Macerated Dark skin
Lopez et al. 2011	96 pre-audit	19	Total pre-audit population Mean age 78.2 years Males 36 Females 60	Arms Legs	Pre-audit Not reported	Pre-audit Dry (69.8) Tissue paper (32.3) Oedematous (17.7) Bruising (35.4) Healthy (23.9)
	95 post-audit	20	Total post-audit population Mean age 78.7 years Males 41 Females 57	Arms Legs	Follow-up audit Not reported	Follow-up audit Dry (67) Tissue paper (27.8) Oedematous (12.4) Bruising (36.1) Healthy (24.7)

Newall et al. 2016	1466	108	Males (46.3) Females (53.7)	Not reported	Unable to reposition Age	Senile purpura Haematoma Previous skin tear
Malone et al. 1991	349	147 (321 skin tears)	Mean age of total population 84.1 years Gender of total population Males 59 Females 290	Head (4.0) Arms (80.0) Legs (14.0) Trunk (1.0) Unknown (1.0)	Impaired mental status 160 (61.0) Normal mental status 101 (39.0)	Nil reported
McGough-Csarny & Kopac, 1998	154	154 (154 skin tears)	Median age 84 Age range 47-106 years Caucasians (88.2) Females (64.7)	Forehead (3.0) Arms (73.0) Legs (20.0) Spinal region (3.0) Right side of body (55.0) Left side of body (45.0)	History of previous skin tears (79.2) Very old Frail Dependent on ADLs Nutritionally impaired Dementia Stiffness Spasticity Sensory loss Limited mobility Poor appetite Polypharmacy	Ecchymosis or senile purpura at site of skin tears 68/146 (46.6) Ecchymosis at other body sites 74/138 (53.6)
Payne & Martin, 1990	10	10 (31 skin tears)	Age range 55-105 years Caucasian 9 Negroid 1 Male 2 Females 8	Arms 24 (78.0) Legs 7 (23.0)	History of skin tears 7 (70.0) Frail elderly Cognitively impaired Bedridden Requires feeding/tube feed	Ecchymosis at site of skin tear 7 (70) Presence of senile purpura Loss of subcutaneous tissue in relation to linear skin tears

Sanada et al. 2015	368	14	Males 94 (25.5) Females 274 (74.5)	Dorsal forearms 9 (64.3) Dorsal hands 2 (14.3) Legs 3 (21.3)	Pre-existing skin tears Lower Braden scale score	Nil reported
Skiveren et al. 2017	128	6 (10 skin tears)	Mean age 88.33 years Age range 68–98 years Males 2 (33.3) Females 4 (66.6)	Arms 4 (40.0) Legs 6 (60.0)	History of skin tears 5 (83.3) Rheumatoid arthritis 4 (66.7) Barthel20-Index < 10 4 (66.7) At risk of falls 5 (83.3) Use walker or wheelchair 5 (83.3) Nutrition risk 4 (66.7)	Ecchymosis 4 (66.7)
White et al. 1994	120	85 (227 skin tears)	Mean age 85 years	Arms 135 (59) Legs 66 (29.0) Other 26 (12.0)	Non-ambulant 109 (48.0) Independently ambulant 93 (41.0) Assistance with ambulation 25 (11.0) Resistant to care	Oedema lower legs Purpura Ecchymosis

Note. Values are number of patients (%).

The review found that the identification of individual and skin characteristics was largely limited by the type of research design and data collection tool used. A detailed discussion of individual characteristics and skin characteristics is respectively provided in sections 2.5.1 and 2.5.2, by chronological order.

2.5.1. Individual characteristics associated with skin tears.

Common individual characteristics reported to be associated with skin tears in the literature included: previous history of skin tears, use of steroidal or non-steroidal medications, very elderly and frail individuals, and those dependent on others for assistance with activities of daily living (Amaral et al., 2012; Malone et al., 1991; McGough-Csarny & Kopac, 1998). Activities of daily living (ADL) generally refer to a distinct set of activities (movement in bed, transfers, locomotion, dressing, personal hygiene, and feeding) that are necessary for general self-caring (Van Dam & De Deyn, 2010). These broad individual characteristics were not consistently recorded across all studies.

A retrospective review of skin tears incidents conducted over a 12-month period in a 349 bed long-term care facility, found that even though 61% of residents who acquired a skin tear had an impaired mental status when compared to residents with no mental impairment the difference was not significant ($p = .375$) (Malone et al., 1991). The failure to identify additional individual factors may have related to the incident reporting system, which may not have been able to capture detailed individual health impactors or recognised their actual or perceived association with the skin tear. A descriptive study by McGough-Csarny and Kopac (1998) identified six factors associated with the risk of skin tears in over 65% of their study population. These factors included advanced age, sensory loss, nutritionally compromised, history of skin tears, impaired cognition, and dependency for ADL (McGough-Csarny & Kopac, 1998). Poor locomotion and ecchymosis occurred in over 50% of the sample, while polypharmacy and use of an assistive device was present in over 40% of cases (McGough-Csarny & Kopac, 1998). Even though these authors outlined a list of risk factors for

skin tears they failed to define these risk terms, making replication of their study and subsequent comparison of study findings difficult.

A skin tear epidemiological and exploratory cross-sectional study conducted in 2010 among 157 Brazilian oncology patients reported individuals with skin tears had lower Karnofsky scores¹ ($p = .031$), lower Braden Scale scores² ($p = .026$), and less collaborative behaviours ($p = .042$) (Amaral et al., 2012). This study however, related specifically to an oncology population aged over 18 years, and was not fully representative of an ageing population. A definition or description of 'less collaborative behaviours' was not provided by the authors to permit comparisons with results from other studies. Despite the term 'less collaborative behaviour' suggesting a level of reduced cooperation, the expression is ambiguous and open to different interpretations.

A 6-hour point prevalence survey conducted at a single long-term care facility of 113 Canadian aged care residents identified anatomical stiffness and spasticity to be associated with skin tears (LeBlanc et al., 2013). The survey demonstrated residents with a Cognitive Performance Scale (CPS) score³ of three and four ($p < .001$) had a significantly higher risk of skin tears in contrast to those with higher scores. Residents requiring significant assistance with eating or movement or having an ADL score of four were reported to be nearly three times more likely to have a skin tear (LeBlanc et al., 2013). The authors also reported a possible relationship between a history of skin tears and the predisposition for skin tears ($p = .046$) (LeBlanc et al., 2013). A limitation of the study was the short 6-hour data collection period, which restricted the capacity to capture more detailed information pertaining to individual characteristics.

¹ An assessment tool for measuring functional impairment with lower scores indicating decreased probability of survival.

² An assessment tool for measuring the risk of a pressure injury with lower scores indicating a higher risk.

³ An assessment tool for evaluating the level of cognitive impairment in aged care residents with higher scores indicating a greater impairment.

A Western Australian non-match case control study, used multivariate analysis to evaluate a broad range of individual characteristics, reported that inability to reposition independently significantly increased the risk of skin tears (Lewin et al., 2016). In a follow-up study, the researchers found that in addition to the inability to reposition independently, age was a significant predictor of skin tears (Newall et al., 2016). A detail discussion of both of these studies is provided in Section 2.5.4.

Multiple logistic analyses of 3-month's incidence data from a Japanese long-term medical facility identified that patients with pre-existing skin tears (odds ratio [OR] 15.42, CI 3.53–67.43) and a 6-point decrease in the total score of the Braden Scale (OR 0.10, CI 0.01–0.83) were significantly more likely to sustain a skin tear (Sanada et al., 2015). This study is also discussed further in Section 2.5.4.

Recently, a point prevalence survey of 140 nursing home residents in Denmark reported a skin tear prevalence of 4.6% with a history of skin tears being significantly associated with new skin tear occurrence ($p < .001$) (Skiveren, Wahlers, & Bermark, 2017). The devised data collection tool appeared to be limited to factors that were commonly reported in the literature to be associated with skin tears.

2.5.2. Skin characteristics associated with skin tears.

An equally broad range of skin characteristics (ecchymosis, senile purpura, fragile skin, dry skin, and oedema of the lower limbs) were identified in relation to skin tears by other authors (Everett & Powell, 1994; Lopez et al., 2011; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; White et al., 1994). Many of these characteristics were based on articles published nearly three decades ago. The skin characteristics identified in the literature that are reported to be associated with skin tears are listed in Table 2.1.

Payne and Martin (1990) were the first to identify two skin characteristics in relation to skin tears after examining a convenience sample of 10 individuals aged 55–105 years with a total of 31 skin tears. Ecchymosis was

reported in 70% (n = 7) of these cases and senile purpura was identified as a risk factor as was a previous history of skin tears, which was reported in 70% (n = 7) of their cases (Payne & Martin, 1990). The authors also noted loss of subcutaneous tissue relating to linear skin tears, but did not provide any further details.

The inability of Payne and Martin (1990) to identify additional skin characteristics may have been related to the narrow list of skin parameters that were included in the data collection tool and the small sample size. A further limitation of this study was the inherent bias associated with using a convenient and relatively small sample, which may not represent the broader aged population, and which potentially undermined the generalisation of their findings (Glasser, 2008; West et al., 2002). A lack of clarity between the terms 'senile purpura' and 'ecchymosis' created ambiguity about whether the authors were referring to the same skin lesion. Nevertheless, the findings from this study was used to devise the Payne and Martin Classification System for Skin Tears, which was later amended to include the extent of tissue loss as a relevant assessment parameter (Payne & Martin, 1990, 1993). The Payne and Martin classification system is considered to provide a seminal taxonomy for skin tears (Carville et al., 2007).

In 1992, a retrospective 6-month documentation audit was conducted in a 347 bed long-term care facility in Western Australia to identify the prevalence of skin tears (Everett & Powell, 1994). Skin 'fragility' was identified in 79% of residents with skin tears, although a formal definition of skin fragility was not provided. The devised data collection tool and the clinical assessors varying level of expertise were potential limitation to the reporting of skin characteristics.

A 6-months prospective descriptive study of a convenient sample of 154 United States of America (USA) Veteran Affairs residents with a total of 154 skin tears reported ecchymosis or senile purpura occurred at the skin tear site in 46.6% (n = 68/146) of cases, while ecchymosis was present at other body areas in 53.6% (n = 74/138) of instances (McGough-Csarny & Kopac,

1998). The authors did not differentiate between the terms 'ecchymosis' and 'senile purpura' and potentially these terms could have been used interchangeably. An explanation was not provided for the discrepancy between the skin characteristic denominator values and the sample population.

White and colleagues undertook a 12-month evaluation study to identify the cause of skin tears in a 120 bed USA residential care facility (White et al., 1994). Skin characteristics reported in association with skin tears included purpura, ecchymosis and lower extremity oedema. Similarly, the definition for purpura and ecchymosis were ambiguous and statistical values were not reported (White et al., 1994).

A pre-audit of 96 acute aged care and rehabilitation inpatients, with a mean age of 78.2 years, was conducted in 2010 at two public hospitals in the Australian Capital Territory using the Joanna Briggs Institute 'Practical Application of Clinical Evidence System and Getting Research into Practice' programmes (Lopez et al., 2011). After the implementation of the skin tear guidelines, a follow-up survey of 95 inpatients with a mean age of 78.7 years was completed. The pre-audit skin characteristics reported included dry skin (69.8%), tissue paper thin skin (32.3%), oedema (17.7%), bruising (35.4%), and healthy skin (23.9%) (Lopez et al., 2011). Comparable results were obtained for the post-audit. The reported skin characteristics related to the total population sampled and not specifically to those patients with skin tears, making interpretation of the study difficult. Since the term 'bruising' was not explicitly defined it is open to several clinical manifestations of interpretation, which are discussed in greater detail in section 2.6.

A Canadian prevalence study of residents within a 113 long-term care facility found that ecchymosis ($p = .29$) was not significantly associated with a greater likelihood of skin tears (LeBlanc et al., 2013). This finding contrasts with previous studies that reported an association between this skin lesion and skin tears (McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; White et al., 1994). A limitation of the data collection tool meant that

ecchymosis, which referred to a lesion that was more than 3 cm² was the only skin characteristic assessed and recorded.

The results of a Western Australian case control study, which was conducted over a 6-month period identified five skin characteristics that significantly predicted the risk of skin tears (Lewin et al., 2016). These characteristics included ecchymosis (bruising), senile purpura, haematoma, evidence of a previously healed skin tear and oedema. In a follow-up prospective cohort study that was conducted over a 12-month period the researchers found that the predictive ability of these characteristics for identifying skin tears was poor (Newall et al., 2016). Secondary analysis that combined data from both studies identified senile purpura, haematoma and evidence of a previously healed skin tear to be better predictors of skin tears. A detail discussion of these studies is provided in Section 2.5.4.

Recently, a Danish study of 140 aged care residents reported ecchymosis to be significantly associated with skin tears ($p < .0001$) (Skiveren et al., 2017). Ecchymosis was defined as “subcutaneous bleeding greater than 3 cm²” (Skiveren et al., 2017, p. 35). The data collection tool was limited to only two skin characteristics that included a history of a previous skin tear (scars) and ecchymosis.

This review found that published skin tear literature largely lacks clinical evidence on the influence that intrinsic and extrinsic ageing had on aged-related skin changes and the associated risk of skin tears. However, an case-control study of elderly Japanese individuals from a long-term medical facility suggested that intrinsic and extrinsic ageing were implicated in skin tear occurrence but did not find any statistically significant association between individual characteristics and the risk of skin tears (Koyano et al., 2014).

The findings of these publications have informed the development of contemporary guidelines and best practice consensus statements (All Wales Tissue Viability Nurse Forum, 2011; LeBlanc & Baranoski, 2011; LeBlanc et

al., 2008; National Guideline Clearinghouse, 2008). The Canadian Association of Wound Care (CAWC) 'Best Practice Recommendations for the Prevention and Treatment of Skin Tears' lists the following individual characteristics as risk factors for skin tear formation: advanced age; female; Caucasian; history of previous skin tears; cardiac, vascular, pulmonary or neuropathic problems; immobility; visually or cognitively impaired; polypharmacy; and dependency of ADL (LeBlanc et al., 2008). Ecchymosis was the only skin characteristic reported to be a risk factor for skin tears (LeBlanc et al., 2008). A similar list of individual and skin characteristics was reported in the International Skin Tear Consensus Panel 'Skin Tears: State of the Science: Consensus Statements for the Prevention, Prediction, Assessment, and Treatment of Skin Tears' document (LeBlanc & Baranoski, 2011; LeBlanc et al., 2008).

The USA Agency for Healthcare Research and Quality Guideline for 'Preventing Pressure Ulcers and Skin Tears' however, did not specify any individual and skin characteristics (National Guideline Clearinghouse, 2008). Nevertheless, this guideline advocated the application of non-adherent dressings for 'frail skin' and recommended the need to use a risk assessment tool (National Guideline Clearinghouse, 2008). The 2011 Welsh best practice statement for 'The Assessment and Management of Skin Tears' identified a history of previous skin tears; presence of ecchymosis; dehydrated skin; prolonged use of corticosteroids; impaired sensory perception; cognitive impairment; visual impairment and advanced age as important individual and skin factors that contribute to the risk of skin tears (All Wales Tissue Viability Nurse Forum, 2011).

This review indicates that many of the purported individual characteristics and skin characteristics associated with skin tears were observational. As a consequence, some of the findings were unsubstantiated and appear to rely on anecdotal or experiential evidence rather than the outcomes generated from quantitative studies, structured clinical research and clinical evidence.

2.5.3. Morphological and physiological skin properties associated with skin tears.

The morphological and physiological properties of human skin undergo lifelong changes due to intrinsic and extrinsic processes. In spite of the considerable advances over the last three decades in biophysical skin analysis of ageing skin properties, only two publications (by the same author) reported using non-invasive technologies to objectively quantify skin properties in an ageing Japanese population in relation to skin tears (Koyano et al., 2014; Koyano et al., 2017).

Koyano et al. (2014) initially used a case-control study design to compare a range of skin properties in 18 patients with skin tears and an equal number of patients without skin tears. An association was identified between skin tears and increased low-echogenic pixels of the subepidermal low-echogenic band (SLEB) of the dermis when using 20-MHz ultrasonography technology. The authors also reported decreased type IV collagen; decreased matrix metalloproteinase-2 (MMP-2); and increased tumour necrosis factor- α (TNF- α) were associated with skin tears (Koyano et al., 2014). These secreted proteins were transepidermally collected using a non-invasive nitrocellulose skin blotting technique that was applied to the skin for 10 minutes. However, in a follow-up prospective cohort study of 149 aged care patients over an 8-month period the same researchers reported the measurement of dermal thickness (using ultrasound) was a more accurate predictor of skin tears (Koyano et al., 2017).

2.5.4. Predictive models for skin tears.

This review identified a paucity of empirical research identifying factors that predicted the risk of skin tears in older individuals. The ready availability of sophisticated statistical software packages permits the opportunity to conduct predictive modelling, a statistical technique that simultaneously explores multiple independent variables to forecast their relative influence on a desired outcome or dependent variable (Katz, 2006; Wakkee, Hollestein, & Nijsten, 2014). Predictive modelling does not apply any preconceived notion

to predict a future outcome, allows for adjustment of known measured confounders, and takes into consideration the interaction between variables (Wakkee et al., 2014). Statistical analysis is used to explore clinically important variables with ostensibly unimportant variables to reveal associations that may be either foreseeable or unforeseeable (Waljee, Higgins, & Singal, 2014).

Three published articles were found that used statistical modelling to predict the risk of skin tears (Lewin et al., 2016; Newall et al., 2016; Sanada et al., 2015). A 6-month non-matched case-control study conducted between 2008 and 2009 in a Western Australian tertiary hospital (Lewin et al., 2016). The researchers collected data on a broad range of characteristics that they had identified from the literature to be associated with the risk of skin tears. Multivariate regression analysis found one individual characteristic and five skin characteristics to be significant predictors for the risk of developing a skin tear (Lewin et al., 2016; Newall et al., 2010). These characteristics included inability to reposition independently, presence of senile purpura, ecchymosis (bruising), haematoma, evidence of healed skin tears, and oedema as variables that significantly predicted the risk of skin tears (Lewin et al., 2016). To test these predictive variables a prospective cohort study was conducted between August 2012 and September 2013 on a sample population comprising of 1,466 tertiary hospital patients aged over 50 years (Newall et al., 2016). Subsequent analysis showed the model to have high sensitivity but low specificity for identifying individuals at risk of skin tears (Newall et al., 2016). Secondary analysis of data from the authors' initial study combined with the prospective cohort study found senile purpura, haematoma, previously healed skin tears, advanced age, and the ability to reposition independently were better predictors of skin tears (Newall et al., 2016).

Sanada et al. (2015) conducted a 3-months prospective cohort study of 368 patients, aged over 65 years, from a long-term medical facility in Japan. Baseline data was collected on a wide range of factors including: pre-existing

skin tear, age, sex, length of hospital stay, Braden Scale scores, body mass index (BMI), immobility, paralysis, articular contracture, medication, comorbidity and nutritional routes. Despite only small numbers of patients (n=14) who sustained skin tears, multiple logistic analyses identified that in this aged population a previous history of skin tears was significantly associated with 15.42 increased odds ($p < 0.001$) of predicting skin tears and a 6-point decrease in the total score of the Braden Scale was associated with 0.10 odds ($p < 0.033$) of developing a skin tear.

2.5.5. Location of skin tears.

Eight studies identified a higher proportion of skin tears occurred on the upper extremities as compared to the lower extremities (Koyano et al., 2014; LeBlanc et al., 2013; Lewin et al., 2016; Malone et al., 1991; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; Sanada et al., 2015; White et al., 1994). Conversely, only two studies reported the lower extremities experienced more skin tears than the upper extremities (Chang et al., 2016; Everett & Powell, 1994). A recent survey of 146 inpatients from two medical wards in a Singapore Hospital found that 43% (n = 6) of skin tears occurred on the upper extremities and 57% (n = 8) occurred on the lower extremities (Chang et al., 2016). The research design was a one day point-prevalence study and the number of skin tears was low. In contrast, the earlier described documentation audit by Everett and Powell (1994) found that 37% of skin tears occurred on the upper extremities compared to 58% over the lower extremities. As the audit, did not involve undertaking skin inspections for evidence of skin tears the accuracy and integrity of the data recorded is not clear.

2.5.6. Skin tear risk assessment tools.

Despite the various recommendations to use a skin tear risk assessment tool to accurately identify individuals at risk of skin tears, no contemporary or validated tool was identified in the published literature (National Guideline Clearinghouse, 2008). A single Skin Integrity Risk Assessment Tool was identified which had been developed by White et al. (1994). The Skin

Integrity Risk Assessment Tool classifies risk data in three groups (I, II or III) to identify individuals at risk of skin tears. Group I risk factors are a history of skin tears within 90 days and the total number of skin tears. Group II individuals met four or more criteria from: impaired decision-making skills, impaired sight, extensive assistance/total dependence for ADL, needing wheelchair assistance, loss of balance, confined to bed or chair, unsteady gait, and bruises. Group III individuals met five or more criteria including: physically abusive behaviour; resistant to ADL care; agitation; hearing impairment; decreased tactile stimulation; ability to propel self in a wheelchair; manually/mechanically lifted; contractures of arms, legs, shoulders or hands; hemiplegia/hemiparesis; partial or total inability to balance or turn body; pitting oedema of legs; open lesions on extremities; senile purpura and dry scaly skin on extremities. Individuals who met three Group II criteria and three or more criteria in Group III on the tool were recommended to be placed in a skin tear risk reduction programme (White et al., 1994).

The reliability and validity of the Skin Integrity Risk Assessment Tool has never been established, and it would be difficult to apply in its current format as the instrument fails to differentiate between the magnitude of risk for individual criteria (White et al., 1994). The use of this tool is dependent on a comprehensive assessment of individuals, which is time consuming and may explain the lack of validation or reported use in the literature. Application of this tool in its present form may lead to the implementation of unnecessary and costly preventive measures.

2.5.7. Skin characteristics terminology.

This review of the skin tear literature identified a lack of consistency within the literature on the definition and classification of skin characteristics. There appears to be disagreement in defining and reporting vascular skin lesions that commonly manifest across the extremities of older individuals. The review identified four vascular skin lesions reported to be associated with skin tears, which were: ecchymosis, purpura, bruising and haematoma

(Lewin et al., 2016; Lopez et al., 2011; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; White et al., 1994). These lesions were not consistently reported by all authors and when they were used the terminologies were often poorly defined, used interchangeably or open to misinterpretation.

Lewin et al. (2016) identified five skin characteristics associated with skin tears which included: ecchymosis, senile purpura, haematoma, evidence of previous skin tears, and oedema. The authors referred to ecchymosis as a bruise, with no further description. Senile purpura referred to a manifestation that occurs when “blood vessels become thinner and more fragile, leading to the appearances of haemorrhaging” (Lewin et al., 2015, p. 4). While this description is consistent with White et al. (1994, p. 95), it is poorly described in terms of location, colour, margins, blanching status and palpation status. The term haematoma was defined as a “collection of blood or a clot within the tissues, flap or realigned skin” (Lewin et al., 2015, p. 4). While this definition is commonly accepted, it was unclear whether the authors differentiated between the localised superficial collection of blood that can form beneath a skin tear flap and that of a deeper soft tissue haematoma. Haematomas that form beneath a skin flap generally occur from trauma directly associated with the injury whereas deep soft tissue haematomas, which also result from minimal trauma, cause more extensive tissue destruction and necrosis (Gamo, Vicente, Calzado, Sanz, & López-Estebarez, 2010; Kaya et al., 2008; Kaya & Saurat, 2007). Deep dissecting soft tissue haematomas are more commonly associated with the lower extremities (Gamo et al., 2010; Kaya et al., 2008; Kaya & Saurat, 2007). Further investigation is needed to clarify the precise relationship that exists between haematomas and skin tears as they may be induced from the injury rather than contribute to the risk of skin tears.

While “previously healed skin tears” was not defined by Lewin et al. (2015, p. 4), it is reasonable to assume that the authors were referring to cutaneous scar tissue. It is questionable whether all individuals can

accurately recall the aetiology of a particular scar tissue and the precise location of a previous skin tear. Healed skin tears may also be confused with pseudoscar tissue as they have a similar clinical appearance that resembles fine white atrophic scars (Colomb, 1972; Mokashi & Scheinfeld, 2008). Lewin et al. (2016) and Lopez et al. (2011) reported an association between oedema and skin tears, but they did not state whether the oedema was localised or generalised. In addition to purpura and ecchymosis, White et al. (1994) also reported many among their study population had lower extremity pitting oedema, but they did not directly associate the condition with skin tears.

The association between skin tears and oedema needs further investigation since oedema in older age groups primarily occurs in the lower extremities from age-related vascular changes (Thaler, Wirnsberger, Pienaar, & Roller, 2010). Age-related oedema of the lower extremities relates to a range of conditions including chronic venous insufficiency, lymphoedema, congested cardiac failure, renal failure, pulmonary hypertension and dependent syndrome which encompasses immobility secondary to a stroke or associated with severe forms of dementia (Ely, Osherooff, Chambliss, & Ebell, 2006; Sullivan et al., 2013; Thaler et al., 2010; Trayer, Studdiford, Pickle, & Tully, 2013). Various categories of medications are also reported to contribute to lower extremity oedema in the elderly including antihypertensives, antidiabetic and nonsteroidal anti-inflammatory agents (Thaler et al., 2010). The higher frequency of polypharmacy in older individuals also increases the potential for adverse interactions including oedema (Davies & O'Mahony, 2015; Skinner, 2015). It is therefore conceivable that oedema may not be a predictor of skin tears and that where it is localised to the injury it arises from inflammatory processes that are directly associated with the trauma (Roy, 2010).

Lopez et al. (2011) reported bruising to be associated with skin tears, but again did not expand on this characteristic. Payne and Martin (1990) noted that skin tears occurred over areas of subcutaneous haemorrhages of senile

purpura or ecchymosis. It is unclear however, whether these vascular lesions were present prior to the skin tear or occurred subsequent to the injury. Similarly, ecchymosis or senile purpura was identified in a study by McGough-Csarny and Kopac (1998) who also referred to it as a subcutaneous haemorrhage. This general lack of clarity between the various terminologies was recognised when the Skin Tear Audit Research (STAR) Skin Tear Classification System was being tested for reliability among nurses identified as non-experts in wound management (Carville et al., 2007)

Accordingly, the terms purpura and ecchymosis were replaced in the STAR tool by the words 'dusky or darkened' to combat confusion and reflect the possibility of multiple vascular skin lesions (K. Carville, personal communication, August 29, 2014). This assessment tool, which was developed in Australia to classify skin tears, was validated in the WoundsWest 2007–2009 and 2011 state-wide wounds survey (Carville et al., 2007; Mulligan et al., 2011; Mulligan et al., 2009; Mulligan et al., 2008; WoundsWest, 2007). The tool has subsequently been translated into Portuguese, Japanese and Brazilian (Ribeiro, 2013; Sanada et al., 2015; Strazzieri-Pulido, Santos, & Carville, 2015).

2.6. Defining vascular skin manifestations.

The following vascular skin manifestations were determined to be commonly reported as associated with skin tears and are discussed in greater detail below.

2.6.1. Ecchymosis.

The word 'ecchymosis' derives from the Greek word *ekkhumōsis*, and is a general term referring to the extravasation of blood into the skin (Carson, 2010; Griffith, Falto-Aizpurua, & Nouri, 2015). Ecchymotic skin lesions are benign, non-palpable (macular), either rounded or irregular in shape and have a purplish/brown colour (Cox & Piette, 2010; National Library of Medicine, 2013). Lesions that measure less than 2 mm in diameter are commonly referred to as petechiae, while lesions greater than 20-30 mm are

known as ecchymosis (National Library of Medicine, 2013). The two commonly ecchymotic manifestations of ageing skin that were reported in the skin tear literature were purpura and senile purpura. These lesions are generally classified according to their size.

2.6.1.1. *Purpura.*

Purpura, an ecchymotic lesion, derives from the Greek word porphyra and refers to skin lesions that have a purplish discolouration (Griffith et al., 2015). Purpura generally refers to any cutaneous vascular lesion that ranges in size between 2–20 mm (Figure 2.3). Permission to reproduce this image is provided in Appendix B.

These non-inflammatory, non-blanching, non-palpable lesions, are also referred to as actinic purpura, occur on exposed skin surfaces such as the dorsal forearms and hands of older individuals (Schwartz, 2016). Skin purpura is the result of extravasation of blood cells secondary to vascular fragility and a decline in connective tissue support of the vascular plexus, from aged-related and photoaged-related dermal changes (Cox & Piette, 2010; Husain, Cohen, Schwartz, & Lambert, 2011). Within the skin, the microcirculation is primarily located in the papillary plexus with the basement membrane of the DEJ providing sufficient thickness to protect the vascular bed from shearing forces (Roddie, 2011). Exposed skin surfaces, such as the dorsal forearms and hands, have accelerated aged-related decline in collagen and elastic fibres that lead to decreased connective support of microvascular tissue (Gloster Jr, Gebauer, & Mistur, 2016; Leo & Sivamani, 2015). The cumulative exposure of skin to UV radiation is reported to contribute to the manifestation of purpuric skin lesions (Durai, Thappa, Kumari, & Malathi, 2012; Kocsard, 1967; Minkis, Swary, & Alam, 2016).

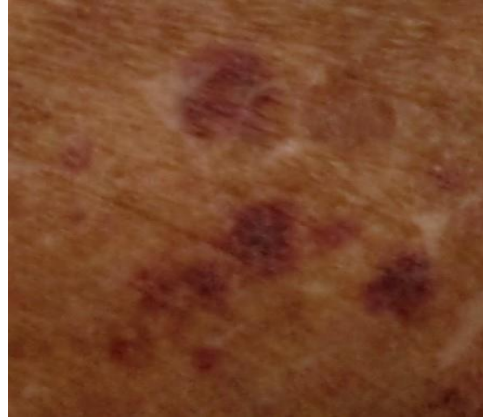


Figure 2.3. Purpura on the dorsal forearms. (Reproduced with permission from Silver Chain).

2.6.1.2. *Senile purpura.*

Senile purpura, which is also referred to as actinic purpura, Bateman's purpura, traumatic purpura or corticosteroid purpura is not a recognised MESH term (Norman & Young, 2014). The clinical manifestations of senile purpura however, vary considerably in size but appear as more extensive ecchymotic lesions across skin surfaces than purpura (Lotti, Ghersetich, Comacchi, & Panconesi, 1996; Sandberg-Cook & Blair, 2013). Senile purpura manifests as non-palpable lesions that are greater than 20mm in diameter (Figure 2.4). Permission to reproduce this image is provided in Appendix B.



Figure 2.4. Senile purpura on the dorsal forearm. (Reproduced with permission from Silver Chain).

2.6.2. Bruise.

A bruise, otherwise known as a contusion, refers to localised extravasation of blood that arises from a non-penetrating blunt force or crush injury that causes characteristic bluish-purple discolouration of the skin and subcutaneous tissue (Bilo, Oranje, Shwayder, & Hobbs, 2013; National Library of Medicine, 2013; Randeberg et al., 2007). Bruises initially appear with a bluish-purple discolouration that progressively dissolves within 2-3 weeks (Cox & Piette, 2010). These lesions undergo characteristic colour changes that range from red, blue and purple in the first 5 days, green after 5-7 days, and yellow after 1-2 weeks (Cox & Piette, 2010).

The use of the word 'bruise' within the skin tear literature appears to be synonymous with the term ecchymosis (Beechey, Priest, Peters, & Moloney, 2015; Lloyd-Jones, 2011; Newall et al., 2016; Stephen-Haynes & Carville, 2011; Thompson-McHale, 2016; White, 2001). Caution is needed when using these terms interchangeably as a prominent medical reference resource, the Stedman's Medical Dictionary (2016) advises against associating the term 'bruise' with any haemorrhagic lesion other than that which arises from a blunt force injury.

2.6.3. Haematomas.

Haematomas occur where there is sufficient bleeding into subcutaneous tissue to form a localised collection of blood that is physically palpable (Cox & Piette, 2010; National Library of Medicine, 2013). The palpable collection of clotted blood forms a fluctuant, compressible mass deeper within the skin (Bilo et al., 2013). The extent of haematomas is highly variable, with incident-related haematomas presenting beneath intact skin tear flaps or pre-tibial lacerations from trauma (Beldon, 2008; Carville et al., 2007). Individuals on anticoagulants can also develop extensive bleeding of the lower extremities that result in deep dissecting haematomas (Fluieraru, 2015). Dissecting haematomas associated with dermatoporosis predominantly occur between subcutaneous tissue and the muscle fascia where they cause cutaneous ischemia and necrosis (Gamo et al., 2010; Kaya et al., 2008; Kaya & Saurat,

2007). These lesions are a clinical emergency presenting as a localised, warm, reddish and oedematous area (Kaya et al., 2008; Kaya & Saurat, 2007). Dermatoporosis, a recently termed skin condition, is discussed in greater detail in the following section.

2.7. Dermatoporosis.

The review also identified seven additional articles were found in the dermatological literature that referred to the term 'dermatoporosis', which describes a chronic cutaneous insufficiency/fragility syndrome (Gamo et al., 2010; Kaya, 2012; Kaya et al., 2008; Kaya & Saurat, 2007, 2010; Mengeaud, Dautezac-Vieu, Josse, Vellas, & Schmitt, 2012; Saurat, 2007). Despite key search terms not being identified, these articles were deemed important and were reviewed separately as dermatoporosis and skin tears appear to be associated with age-related skin changes and display comparable skin characteristics. Dermatoporosis is reported to become evident between 70-90 years of age (Kaya & Saurat, 2010). In a study of elderly French hospital in-patients, the prevalence of dermatoporosis was found to be 32% among 202 patients whose age ranged between 60-80 years (Mengeaud et al., 2012).

Dermatoporosis refers to the clinical manifestations of ageing skin that results from loss of structural integrity and its protective mechanical function (Kaya et al., 2008; Kaya & Saurat, 2007, 2010). Morphological markers associated with dermatoporosis include skin fragility, senile purpura, pseudoscars and skin atrophy (Kaya et al., 2008; Kaya & Saurat, 2007, 2010). The condition primarily affects the posterior forearms, pretibial area, dorsal hands, pre-sternal area, and scalp (Kaya, 2012). What was novel about dermatoporosis was the associated concept of pseudoscars, which refers to the white, scar-like, stellate or linear lesions that develop spontaneously on the arms or hands of older individuals without a previous break to the skin surface (Bjornberg & Mobacken, 1972; Kobayashi, Tanaka, Ito, Harada, & Aiba, 2008). While pseudoscars may result from traumatic changes and are associated with purpura and cutaneous ecchymosis

(Kobayashi et al., 2008), further investigation is needed to differentiate pseudoscars and to avoid any confusion with scar tissue associated with a previous healed skin tear.

Primary dermatoporosis evolves with chronological ageing and chronic exposure to UV radiation, while secondary dermatoporosis arises from the prolonged use of topical and systemic corticosteroids (Kaya & Saurat, 2007). The complication of skin and biomechanical fragility can lead to delayed healing and the formation of dissecting haematomas (from subcutaneous bleeding), which arises from even minor trauma to ultimately form large areas of necrosis (Gamo et al., 2010; Kaya, 2012; Kaya et al., 2008; Kaya & Saurat, 2007, 2010).

Dermatoporosis has been described as having four clinical stages (Kaya & Saurat, 2007). Stage 1 is characterised by the manifestation of senile purpura, skin atrophy, and pseudoscars. Stage 2 includes cutaneous manifestation of stage 1 and localised lacerations that cause the epidermal layer to separate from the dermal layer. Stage 3 consists of multiple lacerations with complete removal of the tissue and delayed healing. Stage 4 is characterised by dissecting haematomas that cause cutaneous necrosis (Kaya et al., 2008; Kaya & Saurat, 2007). Skin tears may actually be synonymous with the localised and multiple lacerations that are reported to occur across exposed skin surfaces in individuals with dermatoporosis.

Physiological changes attributed to dermatoporosis includes impaired production of hyaluronic acid (extracellular matrix glycosaminoglycan molecule that regulates skin moisture) and elastin, which impairs the biomechanical properties of the skin (Barnes, Ino, Jaunin, Saurat, & Kaya, 2013; Barnes et al., 2010; Kaya & Saurat, 2010). Other morphological skin changes associated with dermatoporosis includes flattening of the rete ridges and solar elastosis (Kurashige, Minemuta, & Nagatani, 2013). Many of these cutaneous manifestations were identified in the skin tear literature, therefore dermatoporosis may be an important but an omitted term for defining and identifying fragile skin in the frail aged. Importantly, it may also clarify the

association between fragile skin and skin tears that has previously been reported in the literature (Everett & Powell, 1994; McGough-Csarny & Kopac, 1998; National Guideline Clearinghouse, 2008; Payne & Martin, 1990; White et al., 1994).

2.8. Chapter Summary

This literature review provides a general overview of the anatomy of the skin and examines the influence that intrinsic and extrinsic factors have on ageing skin. Individual characteristics, skin characteristics and skin properties reported to be associated with skin tears in older individuals were evaluated. The review identified a range of individual and skin characteristics associated with skin tears. These factors however, were not consistently reported in the literature. Where vascular lesions were identified to be associated with skin tears the terminology used was poorly defined. The identification of factors associated with skin tears was largely limited by the research design and data collection tool used. The review found that most of the studies did not examine the impact that intrinsic and extrinsic ageing had on skin properties. Moreover, identified skin characteristics appears to be based on visual examination, with no study reporting physically examining the skin to evaluate texture.

Despite differences between the various study populations, sample sizes, definitions and methodologies, the strength of these studies lie in their concerted efforts to identify risk factors associated with skin tears. Two studies by the same author used non-invasive technologies to quantify ageing Japanese skin properties. The review did not identify any prospective cohort study that comprehensively evaluated a broad range of individual characteristics, skin characteristics or concurrently used a suite of non-invasive technologies to objectively quantify morphologically and physiologically skin properties and to predict the 6-month incidents of skin tears. This review of the literature was used to inform the overall framework, design, measurement tools and methodology for this study. Chapter 3 details the study framework.

Chapter 3

Study Framework and Preparatory Stage

3.1. Introduction

This chapter describes the study framework devised to achieve the two study objectives. The first objective required examination of the feasibility and reliability of using non-invasive technologies to objectively quantify morphological (colour, thickness, elasticity) and physiological (TEWL, hydration, pH, sebum, transepidermal skin proteins) ageing skin properties. The second objective required investigation of statistical associations between baseline individual (including demographics) characteristics, skin characteristics, and morphological and physiological skin properties and the 6-month's incidents of skin tears. In order to achieve these objectives, the study was conducted in three stages, which comprised of a preparatory stage, pilot study and major study.

This chapter also describes the preparatory work undertaken to conduct the study. This work involved the selection of suitable non-invasive technologies to measure skin properties, the design and testing of the assessment and data collection tools to be used throughout each stage of the study, and the testing of investigator proficiency for tool use and measurement among a small sample of 10 volunteers.

Figure 3.1 provides a schematic model of the stages undertaken in this study.

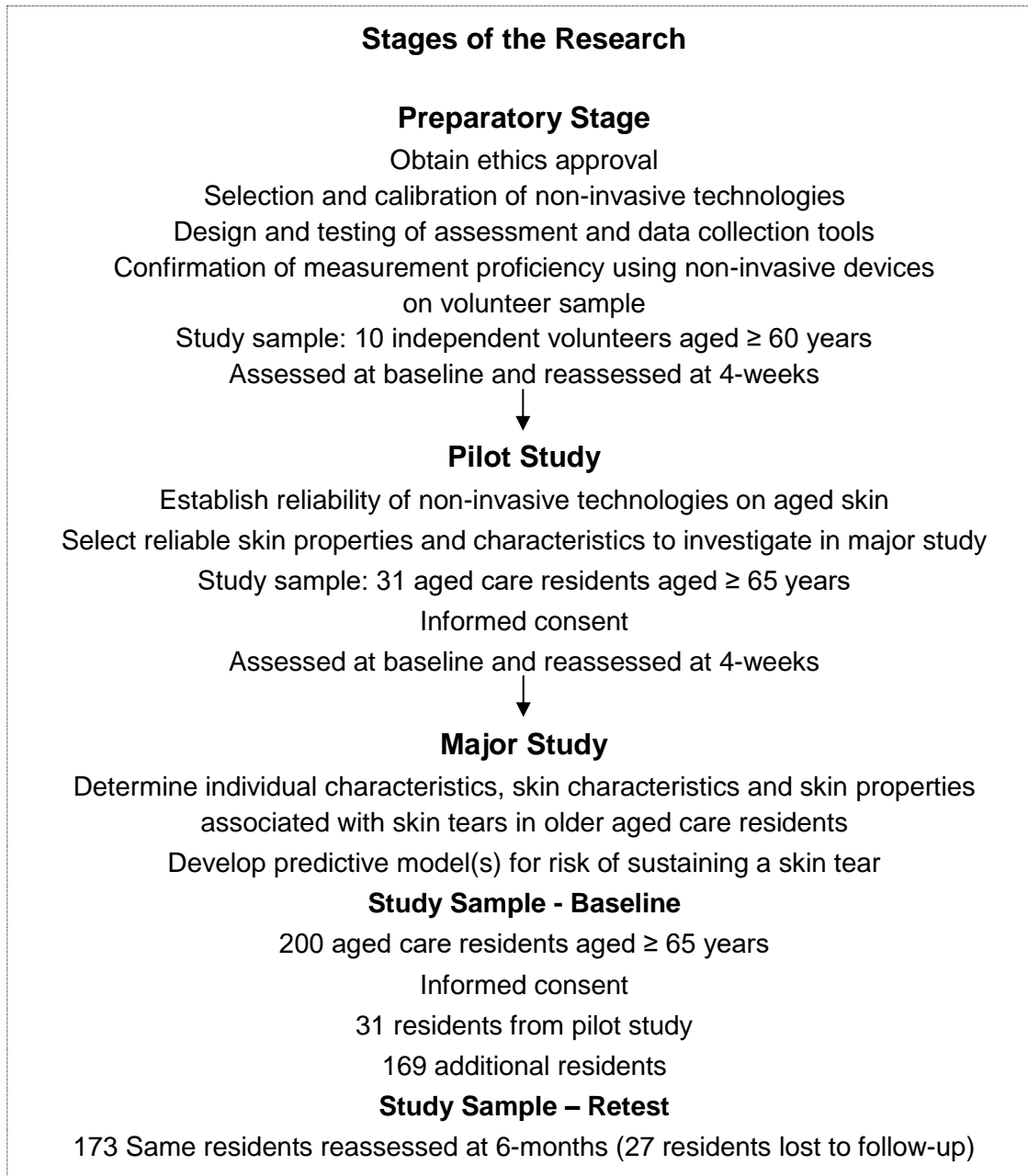


Figure 3.1. Flowchart of the stages of the research project

The preparatory stage of the study assessed the suitability of using various instruments to measure human skin structures in an elderly adult population, and to confirm the proficiency of the investigator to meet international and manufacturer standards when using these non-invasive technologies. This stage also developed the data collection protocols that were applied throughout the subsequent pilot study and major study. Confirmation of the suitability of the data collection tools and the proficiency

of the investigator was then tested by assessing the skin properties at two points in time on a sample of volunteers over a 4-week period. This preparatory stage of the study is discussed in greater detail in Section 3.3.2 and Section 0.

The second stage of the research was a pilot study conducted to address both components of the first study objective, by determining the feasibility and the reliability of non-invasive technologies to objectively quantify morphological and physiological skin properties. The pilot study used a test-retest methodology to assess the utility of non-invasive technologies to evaluate skin properties on a targeted sample of aged care residents at two points in time 4-weeks apart. The test-retest methodology is a recognised approach for determining the reliability and consistency of an device to obtain similar results over two separate occasions (Feder, 2008). The data collected during the pilot study provided a robust dataset to refine the analytical and utilisation techniques for application to the larger sample collected during Stage 3, the major study.

The major study used a prospective cohort study design for the final stage of the research. The major study followed the same methodology applied in the pilot study but the research was conducted on a much larger sample of aged care residents and over a 6-month period, to address the two objectives. This included determining individual characteristics, skin characteristics, and skin properties associated with skin tears in elderly persons and the development of a predictive model(s) for risk of sustaining a skin tear.

3.2. Ethics Approval

Ethics approval for all stages of this study (as summarised in Figure 3.1) was obtained from Curtin University Research and Development Human Research Ethics Committee (RD-23-13) (see Appendix C). Ethics approval was obtained from The Bethanie Group Inc. Governance Committee for the pilot study and major study. The study protocol conformed to the ethical

guidelines of the 1975 Declaration of Helsinki (World Medical Association, 2013).

Informed written consent was obtained from all participants. Participation was voluntary and participants were informed of their right to withdraw at any time in the research process without prejudice or negative consequences. All records were stored in a secured cabinet and will be retained for a minimum of 5 years prior to being destroyed in accordance with national research guidelines (Australian Government National Health and Medical Research Council, 2007). Data collected was accessible only by the researcher and study supervisors.

Specific ethical issues addressed in this study included avoidance of participant discomfort by adjusting measurement technique and test site (see Section 0), conducting the assessment in a secure and private location (see Section 4.2.4) and maintenance and security of personal information through de-identification of data (see Section 4.2.7).

3.3. Preparatory Stage

The preparatory stage of the research was a precursor to the pilot study. It was conducted to evaluate the utility of non-invasive devices to examine aged-related skin properties at a range of anatomical sites, establish the methodological framework, standardise protocols and processes, and to confirm the techniques and settings for operating the devices, which enabled the measurement precision of the data collection tools to comply with the manufacturer's specifications. Figure 3.2 provides a schematic diagram summarising the various steps in the development of the data collection tools and confirmation of the technical proficiency of the investigator to use the various equipment and recording protocols.

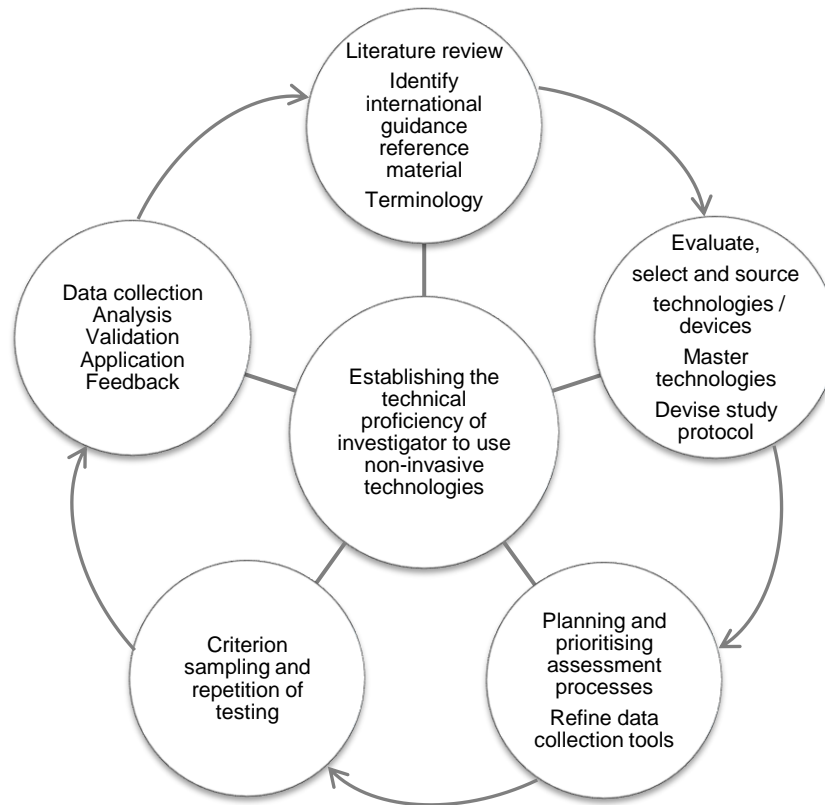


Figure 3.2. Process of establishing investigator's technical proficiency.

The participants' responses to each clinical assessment component were used to refine the methodology and streamline processes to ensure process practices were safe and effective. The technical proficiency of the investigator to use the equipment and apply effective investigative rigor were confirmed by a specialist wound clinician. The suite of non-invasive technologies that were sourced and evaluated in the preparatory stage are described in the following section.

3.3.1. Non-invasive technologies for skin measurements.

Until recently, the majority of studies that have evaluated ageing skin to identify factors associated with skin tears have been conducted using a general visual inspection of the skin (Lopez et al., 2011; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; White et al., 1994). These examinations have provided limited information about skin texture and morphological and physiological skin properties associated with ageing skin. However, with

advances in technologies and wide availability of non-invasive commercial devices, skin properties can now be objectively, quantitatively, and reliably measured without causing harm (Rogiers et al., 1999; Taylor, 2008). The genesis for many of these devices arises from the cosmetic industry where non-invasive technologies have been used for dermatological applications to gently examine human skin (Grove, Zerweck, & Pierce, 2002; Kajs & Gartstein, 1991; Rogiers et al., 1999; Taylor, 2008).

These well-proven technologies were considered to have clinical application as a safe and potentially reliable option for the *in vivo* evaluation of ageing skin properties. The benefits of non-invasive technologies include: the objective evaluation of skin properties to provide immediate results; the opportunity to assess the same anatomical site using a range of devices; the capability to undertake objective follow-up examinations to evaluate the effect of change; and ensures minimal risk of injury to ageing skin (Serup, 2006). The devices that were subsequently selected for the purpose of this study were based on: reliability to non-invasively assess a broad range of skin properties without causing injury; ability to record precise and reliable measurements for some skin types (but not aged skin) over extended periods; portability and potential ease of use in the clinical setting; and capacity to reliably measure skin properties reported in previous studies to be associated with skin tears (Koyano et al., 2014; Taylor, 2008).

The overview of the various non-invasive technologies that were investigated in the preparatory stage of the study for assessing ageing skin properties, is presented in Table 3.1.

Table 3.1. Non-invasive Technologies Used to Examine Skin Properties

Instrument variable	Method	Application
DermaLab Combo® (Cortex Technology, Denmark) Colour	Narrow-band reflectance spectrophotometry	Measures: Erythema (vascularity). Melanin (pigmentation). CIEL*a*b*: L* Evaluates pigmentation. a* Measures the contrast between redness and greenness of an object. Evaluates erythema (redness in pigmented skin). b* Evaluates pigmentation.
Skin thickness	20-MHz B-mode high frequency ultrasound	Measures SLEB, dermal thickness, and skin structural intensity. SLEB and skin thickness values expressed in micrometres (µm). Skin structural intensity presented as an arbitrary score based on empirical research.
Elasticity	Vacuum suction chamber	Measures VE, distensibility and skin retraction properties. VE and distensibility measured in megapascals (MPa). Retraction measured in milliseconds and converted to seconds.
TEWL	Open-chamber device	Evaluates integrity of stratum corneum barrier function under basal conditions. Values measured in grams / sq. metre / hour (g/m ² /hr).
Hydration	Measures skin conductance	Evaluates hydration of superficial stratum corneum layers. Values in µSiemens (µS).
Skin-pH-Meter® (Courage & Khazaka, Germany)	Flat glass electrode measurement	Evaluates skin surface pH/acidity. Measures energy changes from activity of hydrogen cations with the changes in voltage displayed as pH.
Sebumeter® (Courage & Khazaka, Germany)	Photometric evaluation	Quantifies skin surface sebum. Results measured in micrograms per square centimetre (µg/cm ²).
Hadeco Smartdop 30Ex® (Kawasaki, Japan)	Doppler Venous refill time	Toe brachial pressure index. Quantifies venous competency.
Skin Blotting (University of Tokyo)	Measures transepidermal secreted skin proteins collagen IV, MMP-2 and TNF-α	Evaluates effectiveness of dermal- epidermal junction (DEJ) and skin inflammation.

Note. SLEB = subepidermal low echogenicity band; TEWL = transepidermal water loss; MMP-2 = matrix metalloproteinase-2; TNF-α = tumour necrosis factor-alpha.

Three commercially available biophysical skin analysis devices — the DermaLab Combo®, Sebumeter® and Skin-pH-Meter® — were selected to non-invasively quantify a range of morphological and physiological ageing skin properties. These devices have a proven record of use in research as reliable tool for objectively quantifying skin properties. The DermaLab Combo® has been demonstrated to reliably measure variables in studies of: scar tissue; radiation fibrosis; skin barrier function; biophysical differences between gender, age and skin location; breast elasticity and thickness; and topical anti-wrinkle treatments (Anthonissen et al., 2012; Calabrò et al., 2014; Firooz et al., 2012; Gankande et al., 2014; Nguyen et al., 2013; Sutradhar & Miller, 2013; Waring, Bielfeldt, Matzold, Wilhelm, & Butcher, 2011).

The Sebumeter® has been widely used to objectively quantify skin surface lipid levels across different ethnicities, body sites and genders (Kim, Cho, Won, & Cho, 2013; Kleesz, Darlenski, & Fluhr, 2012; Mizukoshi & Akamatsu, 2013). While the majority of these studies related to sebaceous gland activity of the forehead, however, other assessment sites included the neck, ventral forearm, dorsal hand and back (Gerhardt, Lenz, Spencer, Münzer, & Derler, 2009; Yao, Li, Gohel, & Chung, 2011).

The Skin-pH-Meter® has evaluated the acidity of skin surfaces across various age groups, ethnicities and genders (Gerhardt et al., 2009; Luebberding, Krueger, & Kerscher, 2013a, 2014; Wilhelm, Cua, & Maibach, 1991; Yao et al., 2011). These studies assessed the skin surface pH of a broad range of sites including forehead, dorsal and volar forearms, dorsal hands, abdomen, thighs and ankles.

Evaluation of the arterial and venous system of the legs were also examined using a hand held Doppler and photoplethysmography (Hadeo Smartdop 30Ex®) as blood flow can become sub-optimal with ageing (leading to peripheral vascular disease and oedema), which can impact on lower extremity skin properties (Kovacic, Moreno, Nabel, Hachinski, & Fuster, 2011). Transepidermal secreted proteins on the upper and lower extremities were also measured using a skin blotting technique that had recently been

devised by researchers at the University of Tokyo (Minematsu et al., 2014). This technique had been used by Koyano et al. (2014) to identify three transepidermal secreted proteins which were significantly associated with skin tears, including collagen type IV, matrix metalloproteinase-2 and tumour necrosis factor- α (TNF- α).

Aside from the recent skin blotting technique described above, the literature review did not identify any study that used this diverse array of non-invasive technologies to assess ageing skin properties in order to identify risk factors of skin tears. A detailed description of the non-invasive technologies that were investigated in the preparatory stage (and subsequently applied in the pilot and major study) of the study is provided below.

3.3.1.1. *DermaLab Combo®*.

The DermaLab Combo® (Cortex Technology, Hadsund, Denmark) is a portable multicomponent skin analysis device that was used to evaluate skin thickness, TEWL, hydration, elasticity, and colour. The probes used to evaluate the various skin properties were attached to the main module via individual conduits as shown in Figure 3.3.

Contemporary research has demonstrated that the DermaLab Combo® provides precise, reproducible results and is a reliable tool for measuring: fibrotic skin changes; skin barrier function; biomechanical properties; and the effectiveness of topical therapies (Anthonissen et al., 2012; Calabrò et al., 2014; Gankande et al., 2014; Hadi et al., 2015; Kozel et al., 2014; Lodén, von Scheele, & Michelson, 2013; Nguyen et al., 2013; Sutradhar & Miller, 2013; Waring et al., 2011).

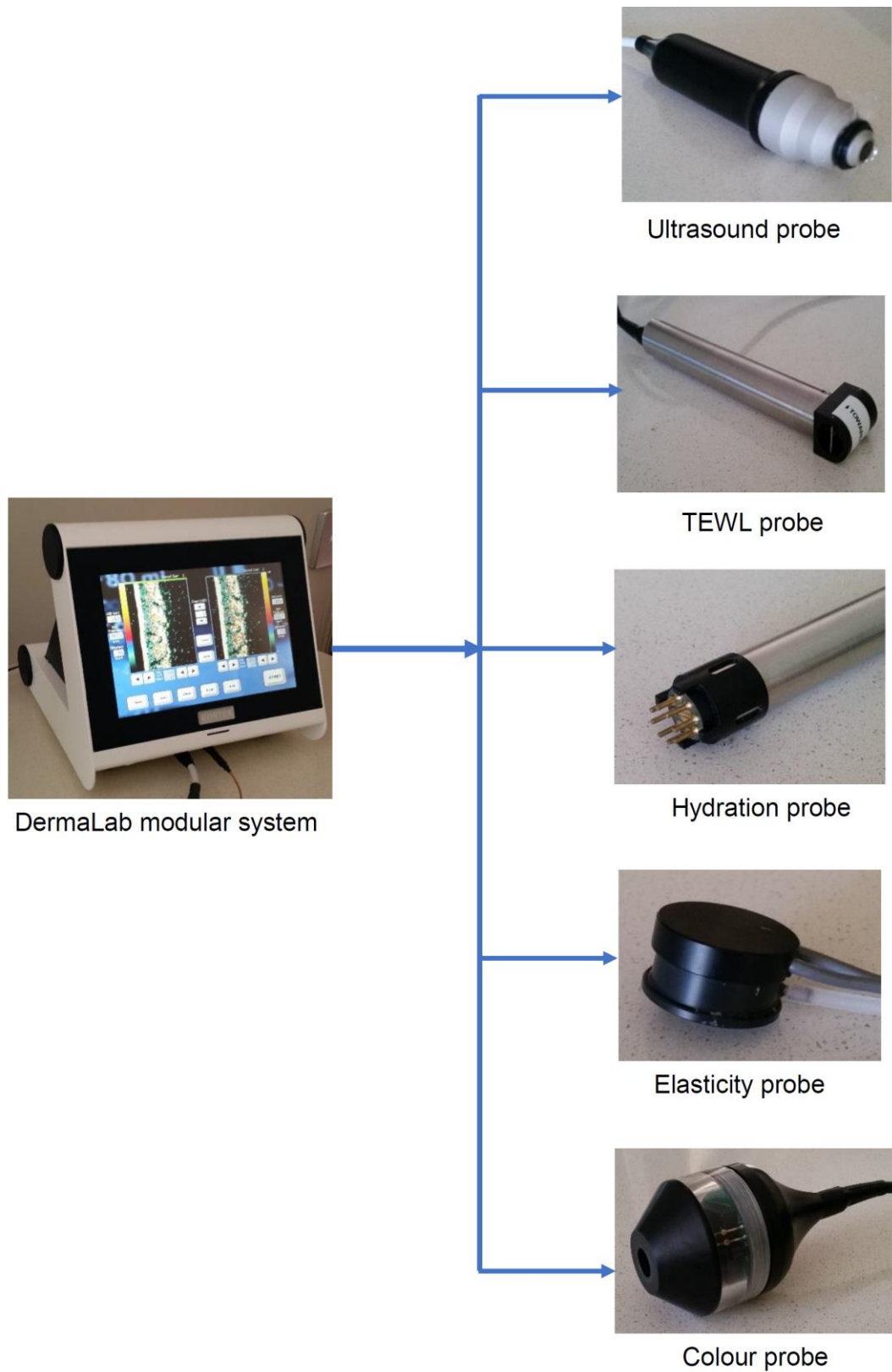


Figure 3.3. DermaLab Combo® modular system with multichannel probe interface.

3.3.1.1.1. *Ultrasound.*

Measurement of skin thickness by high frequency ultrasound may be a useful non-invasive tool for identifying individuals at risk of skin tears. The DermaLab uses a 20-MHz ultrasound, which combines A- and B-mode technologies with a penetrating depth of 3.7mm and a resolution 60 x 200 micrometres (μm) to characterise tissue and measure skin thickness from the epidermis to the dermal-hypodermis interface (Seidenari, 2006; Waller & Maibach, 2005). A disposable plastic film covers the aperture of the probe to permit the transmission of ultrasound waves with minimal attenuation and without interfering with the quality of the image.

The A-mode scanners provide a unidimensional depiction of skin echogenicity that can give misleading results because the dermis-hypodermis interface is not a uniform surface (Seidenari, Pagnoni, Di Nardo, & Giannetti, 1994). In contrast, the B-mode technologies (used in this study) provide a cross-sectional image of the skin to give more reproducible and reliable results by distinguishing the echogenic dermis from the hypoechoic subcutaneous tissue, even though the dermis-hypodermis interface is indistinct (Vogt & Ermert, 2008). The cross-sectional scan generates values for three separate parameters: the SLEB; skin thickness; and skin structural intensity (Pellacani, Giusti, & Seidenari, 2006). Figure 3.4 depicts an ultrasound image of the skin structures of the dorsal forearm of an 87 year old female that was taken with the DermaLab® Combo.

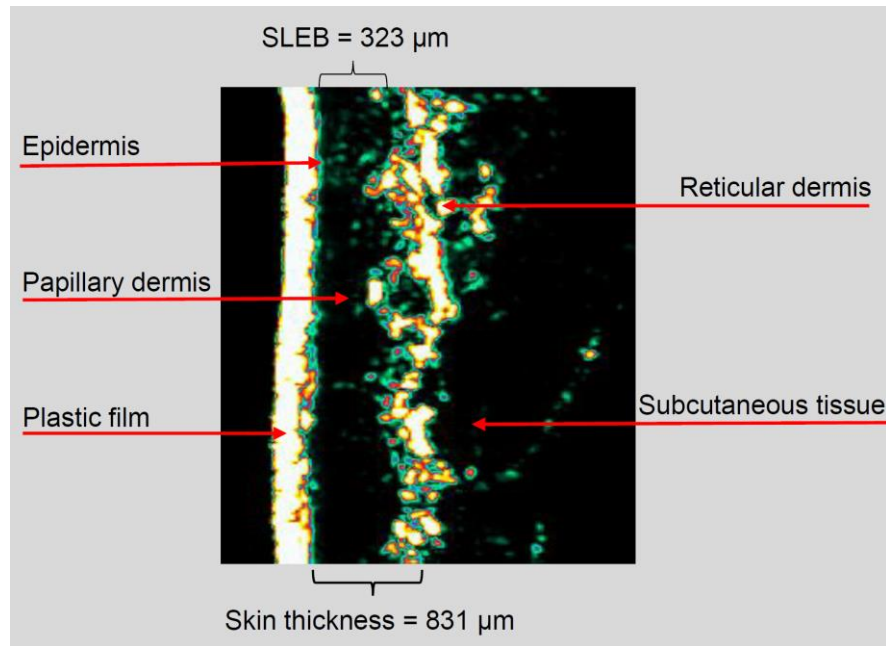


Figure 3.4. Ultrasound image of the dorsal forearm of an 87 year old female.

The SLEB value measures the extent of the dark low echogenicity band at the level of the papillary dermis (Crisan, Lupsor, Boca, Crisan, & Badea, 2012; Micali, Tedeschi, Nardone, & Lacarrubba, 2011; Sandby-Møller & Wulf, 2004). The SLEB has been shown to be a reliable marker for objectively quantifying skin photoageing from degenerative changes to collagen fibres (Gniadecka, 2001). The thickness of skin is measured from the epidermis, which is depicted as a hyper-reflecting band to the dermal-hypodermis interface that is characterised by a hyperechogenic band at the base of the reticular dermis (Vogt & Ermert, 2008).

Both SLEB and skin thickness values are expressed in micrometres (μm). A 50-100 MHz scanner is needed to measure the thickness of the epidermis (Seidenari, Giusti, & Pellacani, 2006). The skin intensity score is a calculation of the average value of the density of dermal collagen, which is an echogenic protein marker synthesised by fibroblasts (Cortex Technology, 2012; de Rigal et al., 1989). Darker colours pertaining to areas of low reflection or poor echogenicity between tissue structures give a low structural intensity score. Conversely, bright yellow, green or red pixels signify stronger

reflection between structures to indicate greater amounts of collagen that give rise to a higher structural intensity score (Cortex Technology, 2012).

3.3.1.1.2. Transepidermal water loss.

Measurement of TEWL may potentially serve as an early non-invasive indicator of skin barrier integrity in older individuals at risk of skin tears. The TEWL probe comprises a lightweight open-chamber with two hygrosensors that are strategically positioned within the aperture to measure temperature and relative humidity, enabling calculation of the evaporation gradient at the skin surface in grams per square metre per hour ($\text{g/m}^2/\text{hr}$) (Grove, Grove, Zerweck, & Pierce, 1999; Rogiers, 2001; Sotoodian & Maibach, 2012). The probe is applied perpendicular to the skin surface as the open-chamber is susceptible to air movement and fluctuations in ambient temperature and relative humidity (Pinnagoda, Tupker, Agner, & Serup, 1990; Rogiers, 2001). The perforated foam of the probe can accrue moisture, which can be controlled by gently moving the handpiece up and down for 20 seconds between successive measurements to reduce water vapour accumulating (Anthonissen et al., 2012).

3.3.1.1.3. Hydration.

Assessment of skin hydration, a determinant of moisture retention capacity of the stratum corneum (SC), may serve as a potential biomarker for skin tears in ageing skin. The hydration probe comprises eight sensory pins that have been specifically designed to reduce the accumulation of moisture during the assessment process, and evaluate skin through body hair and across differing skin surface topography (Grove, Damia, Houser, & Zerweck, 2014). Hydration is an indirect measure of the skin's water content, which is calculated by measuring the electrical conductance at the SC level of the skin (Obata & Tagami, 1990). Conductance results are expressed in micro Siemens (μS) with higher values denoting increased skin hydration (Clarys, Clijsen, Taeymans, & Barel, 2012).

3.3.1.1.4. *Elasticity.*

Evaluation of skin elasticity may serve as an early indicator for skin tears in older individuals. Three elasticity skin properties — distensibility (elevation), retraction and viscoelasticity — were measured using a suction chamber method approach (Serup, 2002). A lightweight plastic probe is attached to the skin surface with a mildly adhesive double-sided tape that creates a closed cavity and reduces artefact arising from movement. Two narrow infrared sensory beams are situated within the aperture of the probe that run parallel to the skin surface to detect skin distension. The gradual application of a partial vacuum distends the skin 2% to the first light sensor to provide a baseline measurement (Grove, Damia, Grove, & Zerweck, 2006). Continuation of the vacuum distends the skin 12% to the second sensor fixed at a distance of 1.5mm above the first sensor (Grove et al., 2006; Serup, 2002). The amount of pressure, measured in megapascals (MPa), that is exerted to elevate the skin from the first to the second sensor is used to calculate the distensibility properties (Young's modulus) of the skin surface. Retraction is obtained by measuring the time in seconds for skin to retract the 1.5 mm from full elevation. The VE value is obtained by dividing the Young's modulus by the retraction time (Grove et al., 2006).

3.3.1.1.5. *Colour.*

Measurement of skin colour may help identify if specific skin types are at risk of skin tears. The assessment of skin colour used narrow-band reflectance spectrophotometry that records results within 1 second. A 7-mm diameter aperture of the optical focus measures: pigmentation (melanin); vascularity (erythema); and colour values based on the French *Commission Internationale de L'Eclairage* (CIE) principles (Marcus, 2014). The melanin index is reported as $M = 100 \times \log (1/\text{intensity of reflected red light})$ and the erythema index as $E = 100 \times \log (\text{intensity of reflected red light}/\text{intensity of reflected green light})$ (Verhaegen, van der Wal, Middelkoop, & van Zuijlen, 2012). Colour results were given as $L^*a^*b^*$ values in the CIELab colour space (Cortex Technology, 2012). The CIEL^{*}a^{*}b^{*} is an abbreviation of the French *Commission Internationale de L'Eclairage* (Everett, Budescu, &

Sommers, 2012). The $L^*a^*b^*$ values permit colour to be reported in a three-dimensional space (Figure 3.5).

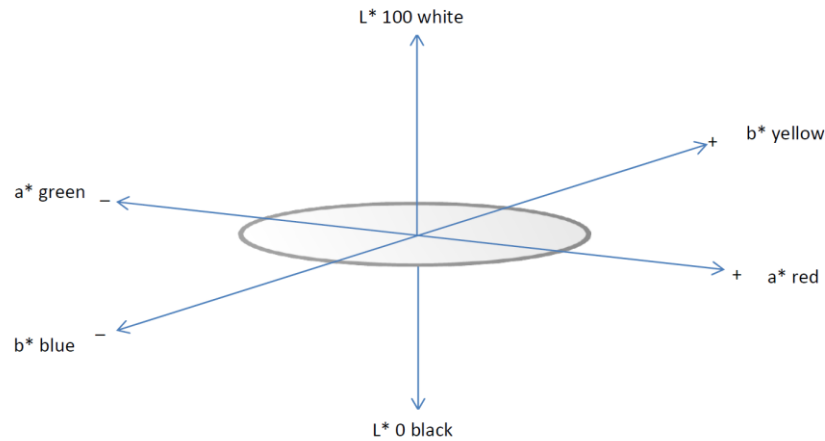


Figure 3.5. Depiction of three-dimensional CIEL a^*b^* colour space

Note. Adapted with permission from Macmillan Publishers Ltd (Weatherall & Coombs, 1992) from 'Skin Color Measurements in Terms of CIELAB Color Space Values', by I.L. Weatherall and B.D. Coombs (1992), *Journal of Investigative Dermatology*, 99(4), p, 469. Copyright permission to reprint Figure 3.5. is provided in Appendix D.

The vertical L^* axis of the colour space represents lightness, with values ranging between 0 for black to 100 for white. The a^* and b^* axes are at right angles to one another across the horizontal axis with the a^* axis signifying green at the negative and red at the positive limit, and the b^* axis denoting blue on the negative and yellow on the positive axis (Kaur & Kranthi, 2012). There are no specified numerical limits for a^* and b^* values. Irrespective of ethnicity human skin is reported to register the same yellow and red hue ranges of the a^* and b^* colour values (Everett et al., 2012).

3.3.1.2. Sebumeter®.

Quantification of sebum may be a useful determinant on skin plasticity and the ability of ageing skin to accommodate deformation. Plasticity, the property of cells to change shape following deformation, is dependent on the hydration level of the SC (Larsen & Jemec, 2002). The Sebumeter® (SM 815, Courage & Khazaka) is a commercially available photometry device with a MultiDisplay Device base unit that connects to a personal computer (Figure

3.6). The device calculates the casual sebum level of the skin surface by measuring the difference in light intensity that passes through an opaque tape (Gabard, Barel, & Clarys, 2014). The casual sebum level is a global term for evaluating skin greasiness and is generally recorded not less than 4 hours after the skin has been cleansed. A special purpose matte film stored within the head of the cartridge is applied to the skin surface for 30 seconds to permit time for the oils of the skin to be absorbed. The transparency of the tape changes after 30 seconds' contact with the skin surface and records values in arbitrary units that range between 0–350 micrograms per square centimetre ($\mu\text{g}/\text{cm}^2$). Figure 3.6 shows an image of the MultiDisplay Device base unit that supports the Sebumeter® and Skin-pH-Meter®.



Figure 3.6. MultiDisplay Device supporting the Skin-pH-Meter® (left) and Sebumeter® (right).

The Sebumeter® has been used to reliably and objectively quantify sebaceous gland activity across different genders, ethnicities and body sites (Kim et al., 2013; Kleesz et al., 2012; Luebberding et al., 2014; Mizukoshi & Akamatsu, 2013). Specific body sites have included the forehead, neck, ventral forearm, dorsal hand, and back (Gerhardt et al., 2009; Yao et al., 2011). In the present study, the measurement of sebum was obtained from the bilateral upper and lower extremities and abdomen in order to identify individuals at risk of skin tears.

3.3.1.3. Skin pH-Meter®.

Measurement of skin pH may serve to determine the integrity and cohesion of the stratum corneum and the ability to resist skin tearing. The Skin-pH-Meter® pH 905 (Courage & Khazaka) with an accuracy of \pm pH 0.1 was used to evaluate skin surface pH. The Skin-pH-Meter® uses the same MultiDisplay Device base unit that supports the Sebumeter®. The Skin-pH-Meter probe (Figure 3.6) comprised of a flat glass electrode with an encased H^+ ion-sensitive solution that measures the skin's fine hydro-lipid pH film layer in volts which are displayed as pH (Luebberding, Kolbe, & Kerscher, 2013; Luebberding, Krueger, & Kerscher, 2013b; Parra, Paye, & The EEMCO Group, 2003). Regular calibration of the probe, using two standard buffer solutions at pH 4.0 and 7.0, is needed to obtain reliable measurements. Prior to each measurement, the pH electrode was rinsed in distilled water and then gently applied to the skin surface for 10 seconds to stabilise the electrochemical potential and optimise skin surface contact (Ehlers, Ivens, Møller, Senderovitz, & Serup, 2001; Gerhardt et al., 2009). The reliability of the Skin-pH-Meter® has been established over different skin surfaces and across various age groups, ethnicities and gender (Ehlers et al., 2001; Gerhardt et al., 2009; Luebberding, Krueger, et al., 2013a; Luebberding et al., 2014; Minematsu et al., 2011; Yao et al., 2011).

3.3.1.4. Hadeco Smartdop 30Ex®.

Identification of arterial and venous status may be useful for identifying vascular changes that could potentially confound the skin measurement results of the lower extremities. The Hadeco Smartdop 30Ex® (Hayashi Denki, Kawasaki, Japan) was selected to evaluate the arterial and venous vascular status of the lower extremities using the toe brachial pressure index (TBPI) and venous photoplethysmography (PPG) modes of the device. Figure 3.7 is an image of the Hadeco Smartdop 30Ex®.



Figure 3.7. Hadeco Smartdop 30Ex® used in this study.

The Hadeco Smartdop®, which has demonstrated good reliability in measuring arterial blood flow has principally been used to evaluate peripheral arterial disease in diabetic patients (Burns & Begg, 2011; Burns, Wegener, Begg, Vicaretti, & Fletcher, 2009; Hoe et al., 2012; Romanos, Raspovic, & Perrin, 2010; Scanlon, Park, Mapletoft, Begg, & Burns, 2012; Zaine et al., 2014). The device has also been used to measure digital pressures in patients receiving haemodialysis and assessing the arterial status of digital rotation flaps (Hurton et al., 2010; Kawakatsu & Ishikawa, 2010). A single published study reported the use of the venous PPG mode of the Hadeco Smartdop 20Ex® (a discontinued unit), with the addition of air plethysmography to evaluate the competency of the calf muscle pump in healing of venous leg ulcers (Simka, 2007). No previous study was identified that reported using the venous PPG mode of the Hadeco Smartdop 30Ex®.

The TBPI measurement can be used to assesses the likelihood of peripheral arterial disease, as toe vessels are less susceptible to medial arterial stenosis that can produce misleading elevated ankle brachial pressure index results (Park, Choi, Ha, & Yang, 2012). The TBPI measurements are automatically recorded by the Hadeco Smartdop 30Ex®, with individuals lying supine in accordance with clinical best practice (Wound Ostomy and Continence Nurses Society, 2008). The Hadeco Smartdop 30Ex® cuff was not used to measure the systolic brachial pressure because older volunteers reported discomfort during the preparatory stage when the automatically inflated cuff exceeded their normal systolic pressure. The

bilateral systolic brachial pressures were therefore manually recorded using an analogue sphygmomanometer to limit the amount of cuff pressure applied to the upper arm. The TBPI was manually calculated by dividing the toe pressure by the highest brachial systolic pressure. The competency of the superficial vein and identification of venous insufficiency was assessed with PPG by calculating the venous refill time in seconds (Kelechi & McNeil, 2010).

The assessment of venous status required individuals to sit at the side of the bed with their legs dependent but not touching the ground. A sensory probe was placed over the posterior tibial vein that is adjacent to the medial malleolus using double-sided adhesive tape. Individuals were required to perform five dorsiflexion's of the feet to partially empty the calf and skin venous reservoirs. Results were calculated when the PPG waveform returned to the initial baseline amplitude on the monitor screen (Hadeco®, 2007).

3.3.1.5. Skin blotting.

A partnership with the University of Tokyo was established to non-invasively examine three transepidermal secreted proteins to determine any differences between these skin properties amongst older Japanese and Australian aged care residents. Transepidermal proteins had previously been shown to be associated with skin tears in an ageing Japanese population (Koyano et al., 2014).

The three transepidermal secreted proteins — type IV collagen, MMP-2 and TNF- α — were measured using blotting sheets provided by the Department of Gerontological Nursing/Wound Care Management at the University of Tokyo. Type IV collagen is a major component of the basement membrane of skin and blood vessels, MMP-2 is a proteolytic enzyme that degrades collagen type IV, and TNF- α is a proinflammatory cytokine involved in mediating inflammation (Koyano et al., 2014).

A single measurement (as shown in Figure 3.8) of the transepidermal secreted proteins was taken on all consenting participants at baseline in the major study.



Figure 3.8. Nitrocellulose membranes blotting sheet.

This involved using a small strip of medical adhesive tape to apply an 8-mm diameter nitrocellulose membrane blotting sheet (dampened with a single drop of normal saline 0.9%) to either the right or left dorsal forearm and either the right or left lateral lower leg for 10 minutes. The need to select one upper and lower extremity for skin blotting was made following consultation with the University of Tokyo, who undertook to analyse the epidermal skin protein blotting test measurements. Random selection of test site was based on their past practice. Test sites were randomly assigned by the flip of a coin. All de-identified blotting papers were forwarded to the University of Tokyo with the results emailed to the investigator.

3.3.1.6. Calibration of devices.

All devices were purchased new, with the manufacturers' manuals outlining the specific scheduling and calibration processes for cleaning, maintenance, and clinical testing. A calibration certificate was supplied by Cortex Technology™ specifying the TEWL probe conformed to strict tolerances based on national laboratory standards. After the recommended warm-up period, all devices were calibrated at regular intervals to ensure the

instruments provided measurements in accordance with manufacturer's specifications.

3.3.2. Data Collection Tools and Development of Assessment Sequence.

A review of the literature identified 11 articles and 16 reference documents that were pertinent to the non-invasive measurement of morphological and physiological skin properties. A list of the recommendations, standards and guidance literature is provided in Appendix E. These documents provided the basis for the study protocol to standardise testing parameters, ensure measurements were reproducible, and results reliable. The study protocol provided the overarching technical, environmental and biological framework for using the devices to assess age-related skin properties and the testing sequence throughout the various stages of the study. This protocol is described in Appendix F.

A component of the preparatory stage was the development of a comprehensive data collection forms to reliably record all assessments and measurements. Three data collection forms were devised and used. The main Data Collection Form (Appendix G) had four sections to record data on individual (including demographic) characteristics; skin characteristics; skin care regimen; and biophysical skin analysis values. Volunteers provided information to complete the first three sections of the data collection tool with the last section of the tool used to record skin property values. When examining the volunteers' skin, a diverse array of visual and physical skin characteristics was identified, which necessitated a Skin Assessment Form being devised for the subsequent stages to record these features. The form (Appendix H) contains two intrinsic, 12 extrinsic, and six additional skin characteristics. The selection of skin characteristics was based on the most common clinical manifestations observed on the skin of volunteers, the skin tear literature, and factors that were reported to contribute to cutaneous ageing (Flament et al., 2013; Lewin et al., 2016; Miyamae et al., 2013; Rayner, Carville, Leslie, & Roberts, 2015).

The descriptive variables were clinically identified as a 'no' or 'yes'. A nominal level classification tool was considered appropriate since a primary purpose of the study was to evaluate non-invasive technologies and not to devise a grading tool of skin characteristics. The grading of skin characteristics would have involved developing and trialling a Likert-type scale where individual items would have needed to be evaluated for reliability and validity. A Location of Skin Characteristic Form, which depicted an anterior and posterior outline of the human body, was developed to ensure consistent recording and coding of the location of each skin characteristic (Appendix I).

3.3.3. Definition of Skin Manifestations.

Inconsistent or incomplete definitions of skin manifestations have restricted comparisons between previous studies as highlighted by the previous literature review. For the purpose of this study a range of intrinsic and extrinsic skin manifestations were assessed including: ecchymosis, bruising, haematoma and elastosis. Ecchymotic skin lesions generally present as non-inflammatory, benign, vascular manifestations on the extremities of older individuals from aged-related changes and not from any underlying medical conditions. For consistency with the medical literature precise definitions were based on the Medical Subject Heading (MeSH) controlled index terms that are listed in the U.S National Library of Medicine's (NLM) biomedical literature database and Medline (National Library of Medicine, 2013).

If terminologies were unavailable under the MeSH headings additional medical literature resources were searched to clarify the definitions. To differentiate between the two ecchymotic manifestations purpura and the more extensive senile purpura (which occur on the extremities of older individuals) they were classified according to their size. In this study 'purpura' referred to the presence of isolated non-palpable ecchymotic skin lesions that ranged in size between 2–20 mm. In contrast, 'senile purpura' referred to the

clinical manifestations of non-palpable ecchymotic lesions that were more extensive than 20 mm.

Cutaneous manifestations of elastosis refer to the appearance of skin across photo-exposed sites that on touch has a coarse, thickened, scaly, dry, and rigid texture compared to adjacent non-exposed skin sites (Patterson, 2016; Raimer, Sanchez, Hubler Jr, & Dodson, 1986). In severe cases, the skin displays a cobblestone or leathery appearance (Figure 3.9). Permission to reproduce this image is provided in Appendix B.



Figure 3.9. Cutaneous manifestations of elastosis dorsal forearm. (Reproduced with permission from Silver Chain).

The vascular skin manifestations assessed in this study are discussed in greater detail in Section 2.6. with the final definitions listed in the Glossary of Terms.

3.3.4. Assessment and Measurement Procedure.

All assessments were performed under standardised measurement conditions and in accordance with the devised protocol that was based on international guidance for the assessment of skin properties (du Plessis et al., 2013; Piérard, 1998; Pinnagoda et al., 1990; Stefaniak et al., 2013). A copy of this protocol is provided in Appendix F. Each volunteer provided a general medical history. A visual examination of the face, neck and extremities was conducted to identify clinical manifestations. The extremities

were physically examined to evaluate the texture of the skin. All information was recorded in a hardcopy format.

The room temperature (accuracy $\pm 0.5^{\circ}\text{C}$) and relative humidity (accuracy $\pm 2\%$) were measured prior to the assessments using a digital hydrothermograph sensor (Testo 608-H2, Lenzkirch, Germany). Volunteers were required to lie on their bed and acclimatise to the clinical environment for a minimum of 15 minutes to permit preconditioning of the skin. During the assessment volunteers were required to lay supine with their arms positioned by their side with the dorsal area exposed to standardise measurements. Skin surface temperature was measured using an infrared non-contact thermographic scanner (Exergen, Watertown, MA). The measurement of skin surface temperature across the various test sites was taken to determine any potential influence on skin property results, in particular the assessment of TEWL (Pinnagoda et al., 1990).

Data was collected across five anatomical test sites: bilateral mid-dorsal forearms (midpoint between lateral epicondyle and radial styloid process), mid-anterior lower legs, and midpoint between the umbilicus and the left iliac crest. The extremities were selected following the literature review, which identified skin tears primarily occurred across these locations (LeBlanc et al., 2013; Malone et al., 1991; Payne & Martin, 1990). The left lower abdominal region was chosen as a control site because: no previous published study reported skin tears in this region; the area was perceived not to be influenced by the effects of extrinsic ageing from UV rays in this sample; and there is generally minimal scarring from surgical procedures. A single event measurement (three consecutive measurements — to check relative precision) of all skin properties were taken 10mm apart at the designated test sites.

The most appropriate sequence to measure morphological and physiological skin properties using the various devices was evaluated to minimise the influence that any single assessment had on successive skin property measurements. Based on the literature the skin properties were

assessed in the following sequence: skin surface temperature; colour; TEWL; hydration; pH; ultrasound variables; elasticity variables; TBPI; and venous PPG. The Study Protocol (Appendix F) and data collection tool (Appendix G) was formatted to reflect this sequence. The bilateral TBPI and venous PPG were then assessed to determine arterial and venous status of volunteers' lower extremities.

3.3.5. Quality Control Process.

A range of quality control measures were established to ensure all assessments were accurate, consistent, and the recorded measurements were reliable. These quality control measures were subsequently adopted throughout each stage of the study and are summarised in Table 3.2.

Table 3.2. Quality Control Process Adopted Throughout Each Stage of the Study

Data Collection	Process	Purpose
Pre-collection	Training	Establish proficiency in the use of non-invasive technologies Devise and refine data collection tool Establish study protocol for the collection of data based on the published literature
Collection	Confirmation	Maintain hardcopy of all assessments and electronically enter all details Undertake face-to-face validity and consistency checks Validate demographic, medical and health variables against facility database or with family members Maintain scheduled calibration of non-invasive technologies Use, store and calibrate equipment according to manufacturer's guidelines
Pre-analysis	Data entry and cleansing	Verify data entry by checking variable range, outliers and missing results against hard copies

3.3.6. Findings of the preparatory stage.

As the objective of this stage was to assess the investigator's proficiency of using non-invasive devices to obtain repeatable and reliable measurements, a formal population sample size was not calculated. The preparatory stage tested all components of the research design including: equipment, calibration of devices, data collection forms and data storage to determine their suitability for conducting the subsequent stages. This was undertaken using 10 independent adult volunteers (4 males and 6 females) aged between 62–83 years ($M = 71.3$, $SD = 6.2$). Assessments were performed in a regulated (temperature and relative humidity) university clinical environment under the supervision of a specialist wound clinician between November and December 2013 at two points in time, 4-weeks apart.

The purpose of the preparatory stage was to establish the methodological framework in preparation for assessing the skin of a sample of aged care residents and exploring the use of non-invasive technologies to examine ageing skin properties. The assessments identified extensive inter-individual differences in skin texture between exposed and non-exposed skin surfaces that influenced the measurement of skin properties. Rigorous control of the testing environment, instrumentation and examination technique were necessary to obtain reproducible skin property measurements across the different test sites, between volunteers, and over the two testing periods. A study protocol was established to provide the technical, environmental and biological guidance for standardising assessments.

During the preparatory stage, a number of technical and clinical issues were identified relating to the selection of the mid-anterior tibial crest surface as a test site. In some volunteers, the anterior tibial crest was pronounced with limited overlaying soft tissue, which proved to be unsuitable as a test site because it did not provide a flat surface for the placement of the various probe heads. The anterior tibial crest surface was also susceptible to discomfort from the sensory pins of the hydration probe where the overlying

soft tissue was lacking. The presence of lower extremity oedema was found to be associated with increased skin stiffness and decreased tissue distensibility, which limited the technical capability of the suction probe to obtain reproducible and reliable elasticity measurements in the mid-anterior tibial crest region. The upper quartile of the lateral lower extremities was therefore selected as an alternative test site, as it provided a flatter skin surface and was less likely to be influenced by oedema.

Due to the selection of the lateral upper quartile of the lower leg as the preferred test site for evaluating lower extremity skin properties, volunteers were required to roll on to their side to place this skin surface in a horizontal position, which is the preferred orientation for assessing elasticity and TEWL skin properties (Piérard & Lapiere, 1977; Rogiers, 2001). The need to change body position however, proved challenging for both the elderly volunteers and the investigator and markedly increased the time needed to complete the overall assessment. Consequently, to reduce the physical impact on volunteers all the assessments were performed with the individual in the supine position. Accordingly, the measurement of lower extremity skin properties was recorded from the lateral rather than the preferred horizontal position.

3.4. Chapter Summary.

The findings of the preparatory stage established: the practicability of using non-invasive devices to assess age-related skin properties; the proficiency of the investigator to use these technologies; the methodological framework, protocol and processes for non-invasively assessing ageing skin; the effectiveness of the data collection tools; and the response of volunteers to assessments. The preparatory stage identified a range of technical, environmental and clinical issues that were addressed through the establishment of a protocol. The preparatory stage provided a constructive context for addressing the methodological challenges involved in studying older individuals and measuring ageing skin properties, and informed the

conduct of the subsequent stages. Chapter 4 describes the two clinical studies conducted to address the first research objective.

Chapter 4

Reliability of Non-Invasive Technologies: Methodology and Results

4.1. Introduction

This chapter describes the two clinical studies that were conducted to address the first research objective of establishing the reliability of non-invasive technologies to assess age-related skin properties. The first clinical study, hereafter referred to as the 'pilot study', assessed the reliability of using non-invasive technologies over a 4-week period and a second clinical study, hereafter referred to as the 'major study' assessed the reliability of using non-invasive technologies over a 6-month period. The chapter provides a detailed explanation of the methods used and description of the results. The findings from the pilot study have been published in the following peer review journal article: Rayner, R., Carville, K., Leslie, G., & Dhaliwal, S. S. (2017). *Measurement of morphological and physiological skin properties in aged care residents: A test-retest reliability pilot study. International Wound Journal*, 14(2), 420-429⁴.

The systematic, quantitative assessment of aged skin has the potential to objectively identify older individuals at risk of sustaining skin tears. Current clinical practice for identifying at-risk persons has largely been based on the subjective assessment of a broad range of individual and skin characteristics. Individual characteristics reported to be associated with skin tears include a history of skin tears, and impaired mobility and cognition whereas general skin characteristics include visible signs of senile purpura, ecchymosis and oedema (Rayner et al., 2015). Prior to this research, only one published study used non-invasive technology to objectively quantify skin properties associated with skin tears (Koyano et al., 2014). No previous study was identified in the literature review that reported the intra-rater reliability and

⁴ Permission to cite this work was approved by the publisher in the online terms and conditions on submission of the article for publication.

test-retest reliability of using non-invasive technologies for objectively quantifying ageing skin properties in association with skin tear incidents.

The purpose of the pilot study was to investigate the intra-rater reliability of using the non-invasive technologies for measuring the skin properties of aged care residents, and the utility of these skin properties from a diagnostic perspective for characterising age-related skin properties. The potential novel applications of these technologies to inform diagnostic investigations are relevant to clinicians and those with a technological background. Those technologies that recorded good reliability in the pilot study were subsequently applied in the major study to assess skin properties on a larger sample of aged care residents.

4.2. Methodology

4.2.1. Study design and setting.

This test-retest reliability study investigated the intra-rater reliability and reproducibility of using non-invasive devices to objectively quantify morphological (colour, thickness and elasticity) and physiological (TEWL, hydration, sebum and pH) skin properties, as well as the vascular status (bilateral TBPI and venous reflux) of aged care residents. The need for researchers to demonstrate reproducibility and consistency of clinical measurements is well documented in the literature since measurement errors affect statistical analysis and the interpretation of results (Kottner et al., 2011; Mulsant et al., 2002).

The pilot study was conducted on 31 aged care residents at two points in time, four weeks apart. Residents who consented to participate in this pilot study were recruited from a single 80-bed residential aged care facility in Western Australia between January and March 2014. The major test-retest reliability study was undertaken across four residential aged care facilities in Western Australia with a total of 360 beds, between February 2014 and June 2015. A total of 200 aged care residents from two regional and two metropolitan facilities were recruited to participate in this major prospective

cohort study. All residential care facilities were operated by a single not for profit service provider.

Prior to conducting the assessments, an educational session outlining the research process was provided to the clinical managers in the residential care facilities and details were circulated among staff at team meetings. Written instructions of the need for participants to avoid bathing and applying moisturisers prior to the assessment were provided, and reinforced through facility buy-in and the support of clinical staff who became champions for the study. All assessments were conducted following consultation with the clinical nurses. The majority of assessments were performed between the hours of 0630 and 1300 under well-controlled and standardised conditions.

4.2.2. Recruitment and eligibility criteria to participate.

Participation of the residential care facilities in this study was made possible with the support of the service provider in consultation with their research coordinator. This service provider is responsible for managing 12 regional and metropolitan aged care facilities in WA. Four aged care facilities were selected for these studies after excluding those facilities that might have generated biased results due to their participation in a separate moisturising study, which was seeking to reduce the incidents of skin tears (Carville et al., 2014).

Residents were recruited to this study if they were aged over 65 years and had provided informed written consent. Residents were excluded if: consent was not obtained; they had a serious medical condition; a connective tissue disorder; were in pain; agitated; had a lower limb amputation; or were receiving palliative services.

An Information Letter was provided to the resident's doctor notifying them of the proposed research and seeking their support (Appendix K). An instructional package containing a Resident Information Sheet (outlining the study protocol and data collection process see Appendix L); a Study Consent Form (to obtain written consent to participate see Appendix M); and a return

prepaid envelope was provided to all cognitively aware participants, or to the legal guardian of participants who were not cognitively aware. If consent forms were not returned within 2 weeks of the postage date the organisation's Research Coordinator contacted the resident or their legal guardian to clarify their willingness to participate in the study. Queries regarding the study or the participants' consent were addressed by either the Research Coordinator or the investigator. Informed consent for residents to participate in this study was obtained under the arrangement of the Research and Development Centre of the service provider.

4.2.3. Sample size.

The pilot study was designed to evaluate the methodological framework, protocol and processes for examining the skin of a representative aged care population in preparation for the future major study. A total of 31 residents were recruited to participate in this pilot test-retest study from a single site of the four identified for the major study. The sample population was considered to be representative of the target resident population and provided sufficient measurement records to permit statistical analysis (Thabane et al., 2010).

The major study replicated the study framework that had been devised in the preparatory stage (Chapter 3) of the research and established in the pilot study. A total of 200 residents aged over 65-years were recruited at baseline to participate in this study. The size of the sample was based on the statistical power to estimate the reliability of test-retest measurements (Hertzog, 2008). An estimated minimum sample size of 160 participants was required to provide 80% statistical power at the 5% level of significance to detect effects from subsequent data analysis and statistical modelling of skin properties as measured by the non-invasive devices at two points in time (Dawson & Trapp, 2001; Peat, Mellis, Williams, & Xuan, 2002). Based on the drop-out rate formula $N = \frac{n}{(1-d)}$ where N is the adjusted sample size before dropout, n is the sample size after dropout and d the dropout rate (20%), an additional 40 participants were recruited for the study to account for likely

attrition from death, transfer of participants or withdrawal from the study (Sakpal, 2010).

Data derived from the retest measurements of the 31 residents who participated in the pilot study was pooled with an additional 169 recruited residents to form the major study's baseline measurements. Pooling of data was considered appropriate since the design and methodology of the major study replicated that of the pilot study with only minor refinements (Charlesworth, Burnell, Hoe, Orrell, & Russell, 2013). The data was combined to reduce the need for unnecessary examinations and to minimise any potential discomfort that multiple assessments could potentially pose to participants (Rosin & van Dijk, 2005).

4.2.4. Assessment procedure.

All assessments were performed in the privacy of the resident's room under standardised temperature ($20\text{--}22 \pm 1^\circ\text{C}$) and relative humidity (40–60%) testing conditions, and in accordance with the study protocol established in the preparatory stage (Appendix F). Data was collected from five anatomical test sites: bilateral mid-dorsal forearms (midpoint between lateral epicondyle and radial styloid process), upper quartile of the lateral lower legs, and midpoint between the umbilicus and the left iliac crest. At each measurement event, three measurements of each skin property were taken 10 mm apart at each test site.

4.2.5. Instruments.

The pilot study evaluated the range of devices described in Chapter 3: the DermaLab Combo®, Sebumeter®, Skin-pH-Meter®, and Hadeco Smartdop 30Ex®. In the major study the same devices, excluding the Sebumeter®, were used to measure skin properties.

4.2.6. Data collection.

The data collection tool that was devised in the preparatory stage was used to record all assessment details for both the pilot study and major study (Appendix G). The data for the first three sections of the data collection tool

were obtained from the resident, their legal guardian, or the medical records. The last section of the tool recorded values obtained from the non-invasive assessment of skin properties. All data was collected in a hard copy format and then manually entered into structured data files for analyses within the Statistical Package for the Social Sciences (SPSS® version 22). Accuracy and integrity of data entry was checked against the retained hardcopy. Data validation, completeness checks, aggregation and initial tabulation of results were then undertaken in SPSS, with any inconsistencies or missing values cross-checked against the hard copy records. A three-step process was undertaken to screen the data files for invalid or missing records. This involved an initial cross-check of all records from hardcopy to data files; generation of frequency tabulations for each variable to identify outlier records for checking; and cross-tabulation of all records to identify missing values or invalid codes.

4.2.7. Data storage.

Throughout each stage of this study consent forms and hard copies of the assessments were securely stored in a locked filing cabinet. The privacy of participants was paramount and hard copies of the assessments were de-identified by using an index number provided by the service provider. This index number was also used in the electronic database, which was secured using an encrypted password that was refreshed every 3 months. The encoded identity key was stored in a separate location, with access to the data only possible by the researcher and study supervisors.

In accordance with national research guidelines, all records will be retained for 5 years in a secure location within Curtin University and will then be destroyed (Australian Government National Health and Medical Research Council, 2007). The publication of results from this study will not identify any participants.

4.2.8. Data analysis.

Data from the pilot study and major study were analysed using SPSS®, with the test sequence and results independently reviewed by a biostatistician. Statistical significance was set at $p < 0.05$ throughout the study unless otherwise stated. The data analysis was undertaken in two parts. The initial analysis determined the intraclass correlation coefficient (ICC) as estimates of the intra-rater reliability over a 4-week period for the pilot study (short term reliability) and over a 6-month period for the major study (longer term reliability).

The ICC is the most popular method for determining test-retest reliability of medical instruments (Vilagut, 2014). The intra-rater reliability relates to the self-consistency and reproducibility of the investigator to obtain similar results over time and under similar testing conditions (Gwet, 2008). The intra-rater reliability for the mean of the single measurement event (three consecutive measurements at each test site) were recorded for both test periods and was analysed using the ICC to assess the reliability or degree of consistency of repeat measures (Kim, 2013). The ICC is designed to assess the consistency between two or more continuous measurements (Gwet, 2008).

The reliability model selected for this study was based on the intra-rater reliability, two-way analysis and fixed effect of the rater, which is consistent with Model 3.2 proposed by Shrout and Fleiss (1979). The model comprised of a one-way random effect with consistency to estimate the reliability (test-retest examination) with a 95% confidence interval. Lin (1989) concordance correlation coefficient (CCC), was also used in this pilot study to complement the measurement of intra-rater reliability. Lin's CCC has been identified as the most appropriate measure of agreement for measuring identical continuous variables (Lin, 1989; McBride, 2005; Zar, 2010).

Both the ICC and the CCC values range from 0 to 1, with a value of one signifying perfect agreement between repeat measurements, while an ICC and CCC value of zero denotes no agreement. Landis and Koch's benchmark scale was used to interpret the ICC, with $\rho < 0$ reflecting poor

reliability, 0–0.20 slight, 0.21–0.40 fair, 0.41–0.60 moderate, 0.61–0.80 substantial and greater than 0.81 almost perfect reliability (Landis & Koch, 1977). In contrast to the ICC, Lin's CCC does not require analysis of variance (ANOVA) assumptions, which can differ according to the type of ANOVA model used (Chen & Barnhart, 2008). Lin's CCC is a more stringent measure of agreement for measuring identical continuous variables (McBride, 2005). McBride (2005) suggested that when interpreting the strength of agreement for Lin's CCC, values < 0.90 is poor; 0.90–0.95 is moderate; 0.95–0.99 is substantial; and > 0.99 is almost perfect. Skin properties that showed moderate to nearly perfect ICC were then tested on the larger aged care sample in the major study.

Values obtained from using the various devices were continuous variables. The TBPI and PPG for venous blood flow values were ranked according to normally reported clinical values (Kelechi & Bonham, 2008; Wound Ostomy and Continence Nurses Society, 2008). Differences in the repeat values for TBPI and PPG for venous blood flow were examined using the Wilcoxon pair signed-rank test. The Wilcoxon signed-rank test, a non-parametric test, was used to determine if the difference between the paired measurements were statistically significant (Rey & Neuhäuser, 2014). The level of statistical significance was set at the 95% confidence interval (CI) with p values > 0.05 indicating no difference between test-retest values. A Bland-Altman statistic was calculated to compare test-retest measurements with the range of agreement defined as the mean bias \pm 2 standard deviations (SD) (95% CI) (Bland & Altman, 1996).

4.3. Results

4.3.1. Consistency of environment conditions for assessments.

Standardisation of the assessment conditions was essential to ensure reproducibility of measurements (Jakovljević & Mekjavić, 2012). The study protocol established in the preparatory stage provided the technical, environmental and biological basis for standardising assessments in this study (Appendix F). Almost all assessments were conducted between 0630

and 1300 hours to standardise the measurement period and comply with the routine of participants and the aged care facilities. Seven participants of the pilot study and four participants of the major study were assessed at 1400 hours.

Variation in environmental factors (room temperature, relative humidity) or skin surface temperature can influence skin property measurements, in particular TEWL (Pinnagoda et al., 1990). To identify any variation between the assessment environments, the mean and standard deviation (*SD*) of the room temperature and relative humidity were recorded for all participants at the beginning of the assessments. The mean and *SD* of the room temperature and relative humidity for the test-retest periods are presented in Table 4.1. The mean temperature for each of the assessments were at the upper limits of the international guidance recommended range of between 20-22 ± 1°C, while the relative humidity was within the recommended 40-60% range (du Plessis et al., 2013; Rogiers, 2001; Stefaniak et al., 2013).

Table 4.1. Environmental Conditions During Assessments Conducted in the Pilot and Major Study

Room temperature and relative humidity	Pilot study		Major study	
	Test <i>M (SD)</i>	Retest <i>M (SD)</i>	Test <i>M (SD)</i>	Retest <i>M (SD)</i>
Temperature	23.1°C (1.2)	22.9°C (1.1)	22.5°C (1.1)	22.6°C (1.4)
Relative humidity	50.3% (4.7)	49.9% (4.9)	50.9% (6.6)	50.0% (6.7)

Note. *M* = Mean, *SD* = standard deviation.

Preconditioning of participants prior to measurements was examined by recording the skin surface temperature from the five test sites. The *M* and *SD* of participant's skin surface temperature by test site for both test periods are reported in Table 4.2.

Table 4.2. Mean Skin Surface Temperature Results by Anatomical Test Sites for the Pilot and Major Study

Skin surface temperature	Pilot study		Major study	
	Test <i>M (SD)</i>	Retest <i>M (SD)</i>	Test <i>M (SD)</i>	Retest <i>M (SD)</i>
Right arm	31.75 (.91)	31.92 (.76)	31.87 (1.09)	31.84 (.93)
Left arm	31.70 (1.04)	31.80 (.88)	31.91 (1.07)	31.91 (.98)
Right leg	31.37 (.92)	31.56 (1.02)	31.51 (1.21)	31.77 (1.16)
Left leg	31.21 (.86)	31.49 (.89)	31.56 (1.15)	31.82 (1.10)
Abdomen	32.77 (0.96)	32.61 (0.97)	33.02 (0.91)	33.30 (0.84)

Note. *M* = Mean, *SD* = standard deviation.

The skin surface temperatures obtained for the upper and lower extremities in this study confirmed that participants had preconditioned to their room and the measurement of skin properties was unlikely to have been influenced by the environment or skin temperature. The abdomen temperature result for both test periods were marginally higher.

Table 4.2 confirms the skin surface temperature for all test sites on the participants had been acceptably preconditioned to their room, and that over the 4-week and 6-months test-retest periods the room temperature, relative humidity and skin temperature measurements were relatively stable and unlikely to have influenced the skin property results. These results are consistent with the literature, which report that at ambient room temperatures of between 20–22°C the skin surface temperature is generally in the range of between 28–32°C (Pinnagoda et al., 1990; Tupker & Pinnagoda, 2006).

4.3.2. Baseline profile of study participants.

Table 4.3 summarises the baseline profile of participants by age, gender, Fitzpatrick skin type, previous history of skin tears, BMI, medications and underlying comorbidities. The proportion of males and females in both the pilot study (*n* = 31) and the major study (*n* = 200) samples were the same, and both samples had a similar median (*M*) age. The Fitzpatrick skin type I to IV (of a 6-factor scale) were represented in both samples. The Fitzpatrick Skin Type Tool, which was originally developed to predict the reactivity of

skin to photochemotherapy is more commonly used in research to identify the clinical sensitivity of skin to UV exposure and sun protective behaviours (Fitzpatrick, 1988; Ravnbak, 2010; Sachdeva, 2009). The median BMI was also similar for both samples. The BMI provided an estimate of an individual's general adiposity based on their weight divided by the square of their height (kg/m^2) (Messiah, 2013).

Table 4.3. Baseline Profile of Participants in the Pilot and Major Studies

Characteristic	Pilot Study (n = 31)	Major Study (173)
Age		
Median (IQR)	88.3 years (84.3–89.2)	88.5 years (83.4–92.2)
Mean (SD)	87.74 (4.42)	87.40 (6.81)
Gender: Count (%)		
Males	9 (29.0)	50 (29.0)
Females	22 (71.0)	123 (71.0)
Fitzpatrick skin type: Count (%)		
Type 1	6 (19.4)	9 (5.2)
Type 2	10 (32.3)	52 (30.1)
Type 3	14 (45.2)	78 (45.1)
Type 4	1 (3.2)	34 (19.7)
History of skin tears: Count (%)		
Males	7 (46.7)	28 (56.0)
Females	8 (53.3)	61 (50.0)
Body mass index:		
Median (IQR)	27.0 (20.42–33.58)	24.7 (21.7–29.2)
Mean (SD)	27.0 (5.30)	25.56 (5.34)
Medications: Count (%)		
Corticosteroid therapy	15 (48.4)	54 (31.2)
Anticoagulant therapy	4 (12.9)	9 (5.2)
Antiplatelet medication	17 (54.8)	70 (40.5)
Comorbidities: Count (%)		
Heart disease	23 (74.2)	73 (42.2)
Respiratory disease	4 (12.9)	21 (12.1)
Dementia	11 (35.5)	96 (55.5)

Note. IQR = interquartile range; SD = standard deviation.

4.3.3. Intra-rater reliability results.

The results of the intra-rater reliability analyses are presented separately for the pilot study (Table 4.4) and the major study (Table 4.5). A more detailed analysis was explored for the pilot study due to the need to screen

out unreliable variables or measurement sites, prior to embarking on the larger sample collection. The reliability of the measurements obtained using the various devices was examined in both the pilot and major studies by the ICC using the test-retest methodology.

4.3.3.1. Pilot study.

The pilot study evaluated the reliability of the DermaLab Combo®, Sebumeter®, and Skin-pH-Meter® for single event measurements at two points in time, 4-weeks apart. The ICC (including 95% CI) and Lin's CCC were calculated for skin colour (erythema, melanin, and CIEL *a*b*), TEWL, hydration, pH, ultrasound (SLEB, skin thickness, structural intensity), elasticity (distensibility, retraction, and VE) and sebum. The ICC, smallest detectable change (SDC) and Lin's concordance correlation coefficient for the skin properties are presented in Table 4.4.

The ICC values indicate considerable variation between variables and between measurement sites. The intra-rater reliability of the multicomponent DermaLab® device using the ICC was moderate to almost perfect ($\rho = .59-.92$) for TEWL across the upper and lower limbs.

Table 4.4. Reliability Statistics for Measurement of Skin Properties at Five Sites on 31 Residents for Measurement at Baseline and at 4-weeks

Skin Properties	ICC (95% CI)	SDC	Lin's CCC
Melanin			
Right arm	.42 (-.19, .72)	17.21	.29
Left arm	.51 (-.02, .76)	18.05	.33
Right leg	.05 (-1.16, .49)	17.67	.01
Left leg	-.07 (-1.20, .48)	18.18	-.02
Abdomen	-.31 (-1.70, .37)	16.33	-.07
Erythema			
Right arm	.71 (.41, .86)	5.12	.57
Left arm	.67 (.33, .84)	5.81	.54
Right leg	.63 (.23, .82)	5.40	.50
Left leg	.62 (.22, .82)	5.21	.48
Abdomen	.41 (-.22, .71)	4.71	.30
CIE L			
Right arm	.71 (.39, .86)	10.57	.54
Left arm	.68 (.36, .85)	12.91	.51
Right leg	.47 (-.09, .74)	12.75	.30
Left leg	.32 (-.40, .67)	14.50	.18
Abdomen	.35 (-.34, .69)	14.38	.22
CIE a			
Right arm	.17 (-.72, .60)	7.87	.19
Left arm	.01 (-1.07, .51)	7.87	.09
Right leg	.32 (-.39, .67)	8.55	.28
Left leg	.31 (-.43, .66)	8.06	.27
Abdomen	.37 (-.30, .70)	8.44	.28
CIE b			
Right arm	.21 (-.62, .69)	6.33	.14
Left arm	-.03 (-1.13, .50)	7.03	.07
Right leg	.36 (-.33, .69)	7.57	.28
Left leg	.57 (.12, .79)	6.76	.44
Abdomen	.19 (-.67, .61)	13.42	.10
TEWL			
Right arm	.92 (.83, .96)	2.03	.84
Left arm	.86 (.71, .93)	2.71	.74
Right leg	.59 (.16, .80)	2.99	.49
Left leg	.79 (.55, .90)	2.84	.65
Abdomen	.02 (-1.01, .53)	3.13	.21
Hydration			
Right arm	.85 (.70, .93)	45.25	.74
Left arm	.77 (.52, .89)	62.02	.63
Right leg	.78 (.54, .90)	62.21	.64
Left leg	.75 (.48, .88)	70.67	.60
Abdomen	.53 (.04, .77)	122.93	.41
pH			
Right arm	.88 (.75, .94)	.56	.78
Left arm	.76 (.51, .88)	.73	.61
Right leg	.86 (.71, .93)	.47	.75
Left leg	.79 (.58, .90)	.51	.66
Abdomen	.83 (.65, .92)	.46	.71

SLEB			
Right arm	.99 (.98, .99)	37.49	.95
Left arm	.99 (.97, .99)	61.46	.97
Right leg	.96 (.92, .98)	79.01	.92
Left leg	.96 (.92, .98)	72.85	.96
Abdomen	.95 (.89, .98)	58.06	.90
Skin thickness			
Right arm	.98 (.96, .99)	116.68	.92
Left arm	.95 (.90, .98)	216.16	.91
Right leg	.99 (.97, .99)	127.86	.94
Left leg	.98 (.96, .99)	158.29	.96
Abdomen	.99 (.99, 1.00)	92.90	.99
Skin intensity			
Right arm	.61 (.20, .81)	24.33	.44
Left arm	.75 (.50, .88)	19.90	.59
Right leg	.59 (.15, .80)	33.89	.41
Left leg	.71 (.39, .86)	29.89	.53
Abdomen	.75 (.48, .88)	30.85	.59
VE			
Right arm	.91 (.81, .95)	.78	.82
Left arm	.67 (.32, .84)	.68	.47
Right leg	.80 (.59, .90)	1.27	.65
Left leg	.76 (.51, .89)	1.54	.61
Abdomen	.87 (.73, .94)	2.42	.77
Distensibility			
Right arm	.12 (-.81, .57)	8.99	.06
Left arm	.80 (.59, .90)	2.57	.66
Right leg	.80 (.57, .90)	1.91	.68
Left leg	.65 (.27, .83)	2.47	.50
Abdomen	.81 (.61, .91)	4.31	.68
Retraction			
Right arm	.92 (.84, .96)	4.57	.85
Left arm	.90 (.80, .95)	2.29	.82
Right leg	.57 (.12, .79)	4.61	.39
Left leg	.78 (.55, .90)	3.32	.64
Abdomen	.99 (.99, 1.00)	.28	.99
Sebum			
Right arm	.34 (-.36, .68)	1.11	—
Left arm	.26 (-.52, .64)	1.22	—
Right leg	.63 (.23, .82)	.35	—
Left leg	.04 (-.97, .54)	.00	—
Abdomen	-.23 (-1.52, .41)	.70	—

Note. TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band; VE = viscoelasticity; ICC = Intra-Class Coefficient; SDC = Smallest Detectable Change; Lin's CCC = Lin's Concordance Correlation Coefficient.

A Bland-Altman plot for the intra-rater agreement mean differences of the right dorsal forearm TEWL is presented in Figure 4.1. The 95% CI of the

mean difference for the right forearm TEWL as established with the Bland-Altman analysis had an acceptable range of approximately ± 2.14 g/m²/hr. The difference was not associated with the value of the mean measurement, which is indicative of the “true” value ($p > .05$).

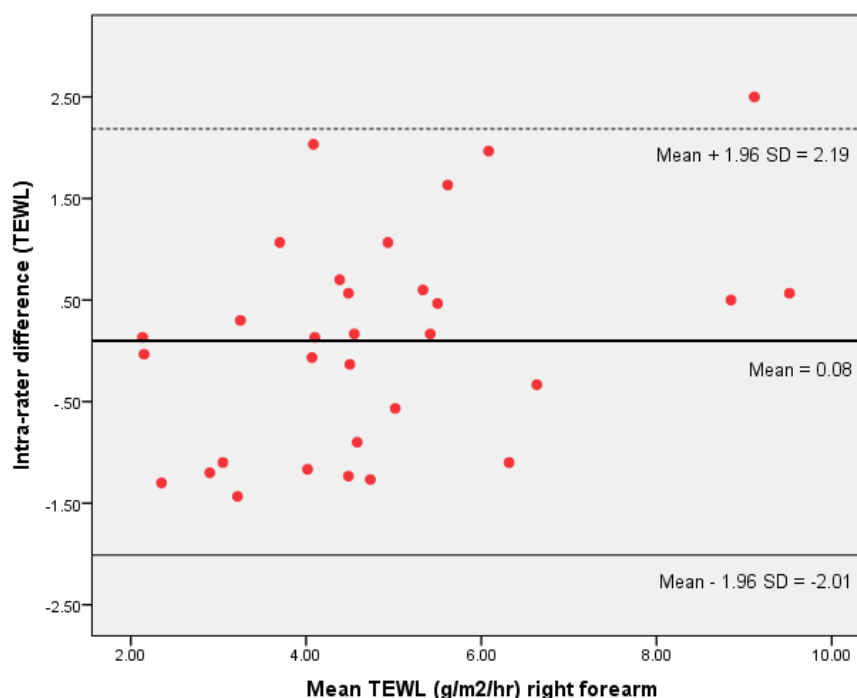


Figure 4.1. Bland-Altman plot showing the difference in test-retest measurements of the TEWL findings for the right forearm on each of the 31 residents.

The intra-rater reliability for distensibility was substantial to almost perfect ($\rho = .65-.81$) at all sites except the right forearm ($\rho = .12$). Test-retest reliability was almost perfect for SLEB ($\rho = .95-.99$) and skin thickness ($\rho = .95-.99$) across all sites. The ICC was substantial to almost perfect for VE ($\rho = .67-.91$) and pH ($\rho = .76-.88$) across all sites. Reliability for hydration ($\rho = .53-.85$) and retraction time ($\rho = .57-.99$) were moderate to almost perfect across all test sites. Test-retest reliability was moderate to substantial for erythema ($\rho = .41-.71$) and skin structural intensity score ($\rho = .59-.75$) across all test sites. Reliability varied from poor to moderate for melanin ($\rho = -.31-.42$); slight to moderate for CIE a* ($\rho = .01-.37$); fair to substantial for

CIE L* ($\rho = .32-.71$) and CIE b* ($\rho = -.03-.57$). The intra-rater reliability scores for assessing sebum was poor to slight ($\rho = -.23-.63$) across all sites.

The results of the comparison between test-retest TBPI and venous PPG values using the Wilcoxon signed-rank test indicate that there was no statistically significant ($p > .05$) median difference over the 4-week period using the vascular assessment device.

4.3.3.2. Major Study.

The intra-rater reliability was determined using the same statistical analysis and tests previously described for the pilot study. Based on the pilot study results, which were discussed in Chapter 5, measurement of erythema, CIE and sebum values were discontinued for the major study.

The non-invasive assessment of ageing skin properties was performed at each of the five test sites on each participant on two separate occasions 6-months apart. The sites were the bilateral dorsal forearms, bilateral upper quartile of the lower legs as well as the left abdominal region. The major study used a larger sample size and time interval to examine the reliability of the DermaLab Combo® and Skin-pH-Meter® over single event measurements and between events (measurements at baseline and again at 6-months) through repeated testing. The results of the reliability testing are presented in Table 4.5.

The test-retest intraclass coefficients for all skin properties measured across the upper and lower extremities indicated good correlation. The ICC was substantial to almost perfect ($> .79$) at a single measurement event both at baseline and again at 6-months measurement events. Over the long-term (6-months), the ICC was substantial to almost perfect across the extremities ($> .63$) and fair to almost perfect at the abdomen ($> .40$).

Table 4.5. Intra-class Correlation Coefficients (ICC) for Measurements of Skin Properties at Five Sites in the Major Study Participants

Skin property	Test site	ICC at baseline (n = 200)	ICC at 6-months (n =173)	ICC at baseline and at 6-months (n =173)
Melanin	Abdomen	.99	.99	.79
TEWL	Right arm	.97	.97	.75
	Left arm	.98	.94	.76
	Right leg	.97	.97	.61
	Left leg	.97	.98	.63
	Abdomen	.97	.96	.40
Hydration	Right arm	.99	.98	.71
	Left arm	.99	.98	.70
	Right leg	.99	.99	.69
	Left leg	.99	.99	.74
	Abdomen	.99	.99	.68
pH	Right arm	.99	.99	.63
	Left arm	.99	.99	.64
	Right leg	.99	.99	.69
	Left leg	.99	.99	.62
	Abdomen	.99	.99	.50
SLEB	Right arm	.97	.98	.96
	Left arm	.97	.98	.98
	Right leg	.98	.98	.87
	Left leg	.97	.98	.91
	Abdomen	.99	.99	.88
Skin thickness	Right arm	.99	.99	.97
	Left arm	.99	.99	.97
	Right leg	.98	.99	.82
	Left leg	.99	.99	.87
	Abdomen	.99	.99	.96
Skin intensity score	Right arm	.90	.92	.66
	Left arm	.93	.94	.71
	Right leg	.95	.96	.78
	Left leg	.94	.95	.71
	Abdomen	.96	.97	.81
Viscoelasticity	Right arm	.82	.86	.83
	Left arm	.87	.89	.84
	Right leg	.78	.83	.70
	Left leg	.80	.84	.74
	Abdomen	.93	.97	.84
Distensibility	Right arm	.86	.85	.78
	Left arm	.83	.85	.80
	Right leg	.79	.83	.75
	Left leg	.84	.79	.66
	Abdomen	.91	.90	.67
Retraction	Right arm	.81	.87	.76
	Left arm	.87	.88	.90
	Right leg	.85	.85	.85
	Left leg	.85	.85	.89
	Abdomen	.97	.96	.91

Note. TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band.

At a single measurement event, both at baseline and 6-months, with measurements taken by the sole investigator the devices provided highly reliable measurements for all skin property variables, but less so for skin intensity score, viscoelasticity, and distensibility. Between measurement events separated by 6-months, the ICC analysis values suggest the measurement values for SLEB and skin thickness on the upper extremities was most highly correlated, whereas the other variables had less similar scores and hence more variability, which may be due to a range of factors other than the reliability of the measurement devices. These include differences in environmental conditions (although study findings show testing conditions were consistent), variation in measurement technique (unlikely with same operator), or the natural physiological changes in skin properties. For each skin property, the ICC values decreased between 4-weeks and 6-months.

The key reliability findings (ICC between baseline and retest measurements) are summarised in Table 4.6 using Landis and Koch's (1977) benchmark scale of reliability.

Table 4.6. Variability of Skin Property Measurements at Each Test Site Recorded in the Major Study at 0 and 6-Months Apart

Skin property (Summary of Table 4.5)	Skin site	Intra-rater reliability	ICC range
Melanin	Abdomen	Substantial	.79
TEWL	Extremities	Substantial	.61–.76
	Abdomen	Fair	.40
Hydration	Extremities	Substantial	.69–.74
	Abdomen	Substantial	.68
Skin pH	Extremities	Substantial	.62–.69
	Abdomen	Moderate	.50
Ultrasound			
SLEB	Extremities	Almost perfect	.87–.98
	Abdomen	Almost perfect	.88
Skin thickness	Extremities	Almost perfect	.82–.97
	Abdomen	Almost perfect	.96
Skin intensity score	Extremities	Substantial	.66–.78
	Abdomen	Almost perfect	.81
Elasticity			
VE	Extremities	Substantial to almost perfect	.70–.84
	Abdomen	Almost perfect	.84
Distensibility	Extremities	Substantial	.66–.80
	Abdomen	Substantial	.67
Retraction	Extremities	Substantial to almost perfect	.76–.90
	Abdomen	Almost perfect	.91

Note. TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band; VE = viscoelasticity.

The Wilcoxon signed-rank test indicated the difference between the medians were not statistically significant ($p > .05$) for the test-retest TBPI and venous PPG values.

4.4. Chapter Summary

This chapter reports the intra-rater reliability results of a single investigator to use these devices over a 4-week (pilot study) and 6-month period (major study). Chapter 5 provides a detailed discussion and implications for examining the association of variables with skin tears.

Chapter 5

Reliability of Non-Invasive Technologies: Discussion

5.1. Introduction

This chapter discusses the intra-rater reliability findings of the pilot and major studies and evaluates a range of non-invasive technologies to assess ageing skin. The findings from these studies address the first key study objective and provides the evidence to support the use of non-invasive technologies for examining ageing skin properties. The pilot study discussion has been published in the peer review journal article: Rayner, R., Carville, K., Leslie, G., & Dhaliwal, S. S. (2017). *Measurement of morphological and physiological skin properties in aged care residents: A test–retest reliability pilot study. International Wound Journal*, 14(2), 420-429.

5.2. Pilot Study Intra-Rater Reliability

The test-retest reliability results for all skin test sites expressed by the ICC indicated that most measurements were reliable. The ICC was almost perfect for ultrasound parameters SLEB ($\rho = 0.95–0.99$), skin thickness ($\rho = 0.95–0.99$) and was substantial to almost perfect for pH ($\rho = 0.76–0.88$) and VE ($\rho = 0.67–0.91$). Hydration ($\rho = 0.53–0.85$) and skin retraction ($\rho = 0.57–0.99$) measurements ranged from moderate to almost perfect across all sites (Table 4.4). The TEWL and elasticity were substantial to almost perfect across four of the five test sites whereas casual sebum levels and most colour parameters showed low ICC. The median difference between the test-retest measurements for TBPI and venous PPG was not statistically significant ($p > 0.05$).

The poor reproducibility for distensibility measurements of the right forearm may in part be associated with the inability to precisely locate the initial test site and underlying elastotic skin changes. Elastotic skin changes manifest where degenerated elastic fibres accumulate in the papillary dermis from chronic exposure to UV radiation and concomitant photoageing of the

skin leading to a decline in functional elastin (Mironov, 2013). In Australia, where motor vehicles are driven on the left-hand side of the road, the right forearm is preferentially subjected to the penetrating effects of UV radiation that adversely lead to skin photoageing (Lewis, Bercovitch, Dill, & Robinson-Bostom, 2004). This influence may have partly contributed to the findings of this study.

The test-retest reliability was substantial to almost perfect for ultrasound measurements of SLEB and skin thickness across all test sites. The SLEB is a hypoechoic band or hypo-reflecting area that manifests in the papillary dermis (Gniadecka, Gniadecki, Serup, & S ndergaard, 1994). This hypoechoic band reflects both structural skin changes associated with ageing and predominates at skin sites that are chronically exposed to UV radiation (Gniadecka, 2001). The SLEB is also associated with oedema that may arise from superficial inflammation or venous hypertension (Gniadecka, 2001). Oedema also has a diurnal component that varies with the time of the day and season, which reduces skin echogenicity and increases the width of the SLEB and skin thickness (El Gammal, El Gammal, Altmeyer, & Vogt, 2014; Gniadecka, 2001). The thickness of skin has demonstrated to significantly increase and the echogenicity significantly decrease in the calf region in the afternoon from the natural gravitational shift in fluid from the upper extremities to the lower extremities (Tsukahara, Takema, Moriwaki, Fujimura, & Imokawa, 2001). This shift in fluid in the papillary dermis can also significantly reduce skin elasticity in the lower extremity (Tsukahara et al., 2001). This natural physiological change reflects the technical importance of adhering to the study protocol of assessing participants in the first half of the day, to ensure assessments are standardised and measurements were not adversely affected.

The intra-rater reliability results were substantial to almost perfect for TEWL and hydration across the upper and lower extremities. The measurement of TEWL has been identified as a reliable means for evaluating the epidermal permeability barrier function under basal conditions (Fluhr &

Darlenski, 2014). Conversely, hydration relates to the ability of the stratum corneum to retain water (Verdier-Sevrain & Bonte, 2007). The TEWL and hydration are readily influenced by a range of individual, environmental and assessment factors including the ambient temperature and relative humidity (du Plessis et al., 2013; Pinnagoda et al., 1990). To minimise the impact of these factors, participants had been requested to avoid applying moisturisers for 24 hours and avoid washing for 12 hours prior to the assessment, as cleansers increase TEWL values and moisturisers inflate hydration results (Rogiers, 2001). Prior to the assessments and to standardise the procedure, participants had also been acclimatised to their room with the test site exposed for a minimum of 15 minutes.

The poorer intra-rater reliability of the TEWL and hydration at the left lower abdominal region compared to the extremities may in part relate to the use of absorbent aids to manage incontinence in some participants. Research has shown that where skin is covered with occlusive absorbent products, TEWL increases (Zimmerer, Lawson, & Calvert, 1986). The inability to precondition the abdominal skin to the environment may also have confounded the results, as some participants were reluctant to expose the test site for the duration of the assessment.

Reliability ranged from moderate to substantial for erythema (redness) and skin structural intensity score across all sites. The Skin-pH-meter® reliability was substantial to almost perfect for pH across all test sites.

The poor to slight intra-rater reliability score for casual sebum levels at all test sites may reflect the lack of sensitivity of the device to measure sebum across non-seborrheic skin surfaces. Despite the widespread distribution of mature sebaceous glands across all skin areas, except for the palms and soles, there are fewer sebaceous glands in the extremities and abdomen compared with seborrheic sites such as the forehead, nose, chin, cheek and upper back (Piérard-Franchimont, Quatresooz, & Piérard, 2010; Rode, Ivens, & Serup, 2000; Sheu, Chao, Wong, Yu-Yun, & Tsai, 1999). The density of sebaceous glands remains constant throughout the life span even though the

level of sebum secretion declines at around 60 years of age (Jacobsen et al., 1985; Pochi & Strauss, 1974). The sebum results for this ageing population was therefore not unexpected as the extremities and abdomen are considered non-seborrheic skin surfaces.

Skin colour values (erythema, melanin and CIEL*a*b*) varied across anatomical test sites. The reliability ranged from poor to moderate for melanin; slight to moderate for CIE a*; and fair to substantial for CIE L* and CIE b*. The lack of agreement for colour may be a consequence of: sensitivity of the spectrophotometry; the relatively small size of the probe head that limits analysis of surface area; imprecision to locate the initial test site at the mid-dorsal forearm; lack of colour uniformity at the skin test sites from photoageing and resulting pigment changes; environmental light; or fluctuations in vascular perfusion that alter the degree of erythema (American Society for Testing Materials, 2009; Balas, 1997; Kasraee, 2017).

To achieve reliability of measurements, skin colour is generally undertaken on non-exposed skin sites such as the volar aspect of the forearm or upper arm to minimise the influence of mottled pigmentation from photoageing (Bologna, 1995; Wee, Beatty, Gozalo-Diaz, Kim-Pusateri, & Marx, 2013). However, these sites can also reflect the tanning response of participants and were not a commonly reported location for skin tears. A range of clinical and environmental factors may also have impacted on the reproducibility of colour values. Increased skin blood flow from any stress or anxiety experienced by participants could have influenced erythema and CIE a* values. Conversely, local vasoconstriction and ischemia may have occurred from excessive pressure when the colour probe was applied to the skin (Balas, 1997).

Similarly, fluctuations in the ambient room temperature, relative humidity, air movement and lighting are known to vary results (Taylor, 2008). While direct lighting was avoided and the time of repeat assessments were similar to the initial test, the examinations were undertaken in a non-clinical environment where ambient temperature and relative humidity could not be

entirely regulated by the investigator. The various facilities and rooms had a range of temperature settings and environmental conditions: some were serviced by centralised air-conditioners, some had individualised air conditioner units, while many lacked air conditioners. Nevertheless, baseline and re-test room temperature and relative humidity were relatively consistent and the readings fell within recommended limits (Pinnagoda et al., 1990; Rogiers, 2001). The poor reproducibility of CIEL*a*b colour space may also have been the result of metamerism where repeat measurements of the test site exhibited colour changes under varying individual, environmental or assessment conditions (Marcus, 1999).

The variability in the ICC results for the 6-months between measurement events for some variables (TEWL, hydration, pH and intensity score) suggest the variability may be due to a range of factors other than the reliability of the measurement devices. These include differences in environmental conditions (although study findings show testing conditions were consistent), variation in measurement technique (unlikely with same operator), or the temporal influence of natural physiological changes in skin properties. For each skin property, the ICC values decreased between 4-weeks and 6-months. This finding is not unexpected and most likely reflects the general intra-individual variability with time.

There was no statistically significant median difference ($p = > .05$) between the test-retest measurements for TBPI and venous PPG according to the Wilcoxon signed-rank test. This finding indicated that these results were reliable over the short term in participants of this study. However, the utility of the PPG to investigate venous insufficiency is questionable in individuals with fixed or restricted joint movement due to the difficulty or inability to perform ankle flexion (Lazarides & Giannoukas, 2007).

5.3. Measurement Issues

In the pilot study the measurement of melanin (pigmentation), colour (CIEL*a*b*) and sebum displayed poor intra-rater reliability across most test sites. While photographs of the initial test site may have improved the

capability to re-measure exactly the same site at second measurement, the literature reports that measurement of colour is more suited to uniformly coloured skin surfaces and it is doubtful whether taking an image would have significantly improved this result (Piérard, 1998). The inability to detect casual surface sebum level in participants suggests a reduction in sebum across the anatomical test sites from age-related skin changes.

The measurement of elasticity parameters (VE, distensibility and retraction), which was obtained using a suction probe with a relatively small 10 mm diameter aperture, is reported to be more suitable for skin that has a softer texture compared to skin that is more rigid and less distensible (Serup, 2002). The accumulation of elastotic material across exposed skin sites and intradermal oedema at the level of the lower extremities are factors that are likely to influence the reproducibility of measurements. In older individuals, lower extremity oedema has a diurnal postural gravitational component as the day progresses that increases dermal thickness and reduces tissue distention (Dobrev, 2014; Gniadecka, Serup, & Søndergaard, 1994).

For ethical, logistical, and methodological reasons the assessments were conducted in a non-clinical environment (the participant's own room) where there was less control over the measurement conditions including room temperature, relative humidity, time of assessment and application of topical skin care products. Variability in any of these factors had the potential to influence the measurement results, its reliability and confound data interpretation. Nevertheless, procuring participant and nursing support in addition to adhering to the established study protocol provided a strong technical basis for standardising skin assessments and mitigating adverse influences.

5.4. Pilot Study Summary

A single assessor non-invasively evaluated the morphological and physiological skin properties of participants at two points in time (4-weeks). Successful measurement of ageing skin properties was conditional on establishing a study protocol that addressed specific technical, environmental

and biological parameters. The overall reliability results obtained on measurement of skin properties in the pilot study demonstrate that non-invasive technologies can safely, practically, objectively and reliably quantify age-related skin properties. All non-invasive technologies could safely assess ageing skin properties with no reports of physical discomfort or skin trauma. Each device was practical in design and portability.

The lack of reproducible results in participants for a range of colour values (across pigmented skin sites) and sebum (over non-seborrheic skin surfaces) indicated these measurements were unreliable and would be unsuitable to retain for measurement in the subsequent major study. Despite the poor ICC value obtained for melanin, this property was considered worthy of further evaluation if the assessment was confined to the abdomen and with minor adjustments to the exposure time of skin to the environment and the amount of probe pressure to improve reliability. If the reliability of measurement were improved, it was anticipated that the assessment of melanin could be used to objectively quantify skin types as the abdomen is generally considered to have uniform colouring compared to the extremities (which on exposed skin sites can be highly pigmented). The measurement of melanin in the abdominal region was conducted to complement the Fitzpatrick skin types, which requires participants to estimate their skin response to UV radiation and is likely to pose a problem in residents with a diagnosis of dementia.

5.5. Major Study Intra-Rater Reliability

Due to concerns about the ability to retain an ageing population the major prospective cohort study was conducted over a 6-month period, and hence across opposing seasons. The assessment of skin properties across contrasting seasons had the potential to influence the findings of some test measurements (du Plessis et al., 2013; Rogiers, 2001). Overall, the 6-months intra-rater reliability for the measurement of skin properties using the ICC ranged between substantial (0.61–0.80) to almost perfect (> 0.81) across the

extremities (Table 4.6). The upper extremities generally recorded higher ICC and more consistent results than the lower extremities (Table 4.5).

The lower reliability results over the 6-months compared to the baseline values may reflect minor differences in environmental and testing conditions, although room temperature, relative humidity (Table 4.1) and skin surface temperature (Table 4.2) measurements were relatively consistent across both test periods. The variation in results for some variables may also reflect changes in measurement technique over time or the natural physiological change in skin properties.

Despite adhering to the study protocol, the intra-rater reliability was only fair for TEWL (.40) and pH (.50) measurements of the abdomen. These lower values compared to the extremities may have related to variations in the skin surface between the first and second measurement events. Additional factors, which may be implicated in the lower ICC for abdomen TEWL and pH was the reluctance by some participants to expose their abdomen under cooler conditions for the duration of the assessment and the possible influence of incontinence aids. A number of studies have reported the relative inability of older adults, compared to younger individuals, to maintain their temperature when exposed to cooler or warmer conditions (Brody, 1994; Evans et al., 1993; Petrofsky, 2012). In the present study, 72.2% of participants experienced some level of nocturia, stress incontinence or urgency that required the need to wear an incontinence pad or aid. Researchers have shown that occlusive incontinence aids or containment products have a pronounced influence on the skin barrier by increasing TEWL and elevating skin surface pH (Aly, Shirley, Cunico, & Maibach, 1978; Rippke, Schreiner, Doering, & Maibach, 2004; Zimmerer et al., 1986). While direct care staff reported adhering to the study protocol and avoided bathing or applying moisturisers to the test sites, some contamination of the abdomen may also have occurred through unintentional exposure to urine or through cleansing the area.

The TBPI and venous PPG test-retest results using the Wilcoxon signed-rank test indicated there was no statistically significant median difference ($p > .05$) using the Hadeco Smartdop 30 Ex® for the left TBPI and venous PPG for the right and left legs. These findings indicate that for the TBPI and venous PPG were unchanged in participants over the 6-month study period and that the results could reliably be used in subsequent analysis.

5.6. Evaluation of Non-Invasive Technologies

5.6.1. DermaLab Combo®.

Direct comparison between the results of both the pilot and major studies, and similar research using the DermaLab Combo® is useful to confirm the reliability of the investigator's methods and measurements. This was not possible however, as no prior studies have been published that tested the intra-rater reliability for objectively quantifying ageing skin properties. Because the DermaLab Combo® uses similar technologies to the manufacturer's previous devices, the DermaScan C® and DermaLab® series for non-invasively examining skin properties, a separate literature search was conducted to investigate these instruments. Three studies on fibrotic scar tissue that previously reported the intra-rater reliability of the DermaScan® (Cortex Technology, Denmark) and DermaLab® (Cortex Technology, Denmark) were located (Anthonissen et al., 2012; Nedelec, Correa, Rachelska, Armour, & LaSalle, 2008; Van Den Kerckhove, Staes, Flour, Stappaerts, & Boeckx, 2003).

Anthonissen et al. (2012) evaluated the intra and inter-rater reliability of the DermaLab® for elasticity and TEWL measurements of burn scars and healthy skin. Measurements were taken on a single occasion, on 24 burn patients aged between 20–69 years ($M = 41.5$, $SD 14.4$ years). The intra-rater reproducibility was examined using Shrout and Fleiss (1979) model 2.1. Model 2.1 calculates the reliability based on a single measurement with absolute agreement. The ICC showed good intra-rater reliability for elasticity (0.90–0.93) and TEWL (0.86–0.88), and good inter-rater reliability for elasticity (0.86–0.93) and TEWL (0.78–0.93) measurements. Compared to

Anthonissen et al. (2012) the intra-rater reliability of the present study was lower for distensibility and TEWL. This may be due to a range of factors including: the length of time between individual assessments; the type of skin surfaces assessed; the age of participants; the different skin test sites; and variation in environmental conditions in terms to temperature and relative humidity.

Nedelec et al. (2008) investigated the intra-rater reliability, sensitivity and specificity of three commercially available non-invasive devices, including the ultrasound scanner DermaScan C® to examine severe hypertrophic scar, less severe hypertrophic scar, donor sites and normal tissue. The study sample comprised 30 patients with an age range of between 19-74 years ($M = 39.2$, $SD 13.3$ years). Shrout and Fleiss (1979) model 3.1 was used to examine the reliability. In model 3.1, the reliability is calculated for all participants by each rater, with the raters considered to be the only interest. Good ICC was reported across the various skin types for total skin thickness (0.82–0.93). A receiver operating characteristic (ROC) curve was used to determine whether the device could distinguish between normal scar and hypertrophic scar. According to the area under the curve (AUC) the model indicated the DermaScan C had excellent discrimination (.998 (95% CI [0.99–1.00], $p < .001$)) for normal scar and hypertrophic scar tissue. The DermaScan C® was reported to have high sensitivity (1.0) and specificity (0.96) and was suitable for discriminating between various tissue types. Even though, the intra-rater reliability of the present study for skin thickness was consistent with Nedelec et al. (2008) direct comparison between the two studies was limited by differences in participants age, test sites, and the types of skin tissue studied. Moreover, participants only rested for a minimum of 5-minutes before assessments were conducted (compared to the recommended minimum 15 minutes that was applied in the present study), which did not permit preconditioning of the skin due to insufficient time to acclimatise to the clinical environment.

In an earlier study, Van Den Kerckhove et al. (2003) evaluated the intra-rater reliability of the DermaScan C® by examining the thickness of scar tissue across 40 skin sites of six participants whose age ranged between 21–72 years ($M = 38.3$, $SD 14.6$ years). The ICC showed good intra-rater reliability (0.98) for the two consecutive measurements. The type of ICC model used in the analysis was not reported and measurements were only taken 5 minutes apart compared to the 6-months interval of the present study. Moreover, the sample size of the population was small ($n = 6$) and participants skin were not sufficiently preconditioned before measurements were taken. Van Den Kerckhove et al. (2003) also reported good inter-rater reliability (0.88) between the two investigators on a single occasion, which contrasts with the present study where a single investigator completed the assessments.

Two additional studies also reported the inter-rater reliability of using the DermaLab® and DermaLab Combo® with both studies relating to the assessment of scar tissue (Gankande et al., 2014; Nguyen et al., 2013). Gankande et al. (2014) examined the inter-rater and test-reliability of three raters to assess melanin, erythema, elasticity and skin thickness of post burn scars using the DermaLab Combo®. Their sample comprised of 30 patients aged between 18–81 years ($M = 43$ years, interquartile range 25–54.3 years). The ICC was interpreted according to Rosner (2006). The ICC for inter-rater reliability was good to excellent for melanin (0.94-0.98), thickness (0.86-0.96) and erythema (0.66-0.84). Test-retest reliability was likewise excellent for melanin (0.87-0.89), thickness (0.92-0.97) and elasticity (0.76–0.91). The test-retest reliability was low (0.29-0.42) for erythema. Direct comparison of the present study with Gankande et al. (2014) was limited by different skin types studied and the different reliability measured used since the authors did not report the intra-rater reliability and the present study only involved a single investigator.

Nguyen et al. (2013) examined the elasticity (distensibility) of radiation fibrotic skin of 69 patients aged between 23–85 years ($M = 54.9$ years) using

the DermaLab® device. Two measurements from either the upper or lower extremities were taken by two investigators, with one measurement taken on a fibrotic skin site and the second measurement taken at a corresponding area on the contralateral extremity. The inter-rater concordance correlation coefficient between clinicians for elasticity values of fibrotic skin (0.82) and normal skin (0.84) was reported to be good. The results of the present study are not directly comparable to Nguyen et al. (2013) as radiation induced skin changes were not evaluated. Fibrotic-like skin changes were however, evident in some participants of the present study across exposed skin surfaces from life-long exposure to UV radiation and in those participants with long-term venous hypertension and chronic oedema of the lower extremities.

5.6.2. Sebumeter®.

Despite the Sebumeter® (Courage + Khazaka, Cologne, Germany) being the most commonly used device to objectively quantify sebum production, no published literature was identified that specifically reported assessing the intra-rater reliability. A single study by Arbuckle et al. (2009) reported using the Sebumeter® on a subgroup of 152 participants aged between 18–70 years with oily facial skin at two points-in-time, 4-10 days apart. The test-retest reliability of the Sebumeter® was not reported to limit comparison with the present study.

5.6.3. Skin-pH-Meter®.

A single study by Lavender et al. (2011) reported the intra-rater reliability of three non-invasive technologies, including the Skin-pH-Meter, to assess TEWL, hydration and pH of neonates with ($n=30$) and without atopic eczema ($n=50$). Consecutive measurements were taken of three sites (upper abdomen, upper leg and forearm) within 24-hours of birth, at 4-weeks and again at 8-weeks. The study reported an ICC greater than 0.92 for all repeated measurements. In contrast, the intra-rater results of the present study for TEWL, hydration and pH were lower than that reported by Lavender et al (2011). Direct comparison of the reliability results of the present study

with Lavender et al. (2011) was not possible due to the substantially different study populations in terms of age, test sites and exposure of skin properties to extrinsic factors.

5.7. Major Study Summary

A range of non-invasive devices were used in the pilot study and the major prospective study to measure ageing skin properties. The results of the major study demonstrated the ICC over the short-term was consistent with the pilot study. The use of the DermaLab Combo® and Skin-pH-Meter® showed good reliability and were suitable for objectively quantifying a range of ageing skin variables under well calibrated and controlled measurement conditions. The devices permitted the objective evaluation of skin *in vivo* and were safe for use in this ageing population. The short-term intra-rater reliability was good to excellent and, as expected, better than the long-term reliability. Long-term reliability incorporates natural biological age-related skin changes. While the ICC obtained for the extremities remained substantial to almost perfect, measurements of the upper extremities were generally more consistent than the lower extremities. Except for melanin, which continued to be assessed to confirm skin type classification, abdominal skin properties measurements were considered to have insufficient clinical relevance to the risk of skin tears to be included in any further analysis.

The findings of this study add to the limited published literature on the intra-rater reliability of using non-invasive technologies to examine ageing skin, and provides a useful basis for further research. The intra-rater reliability for these advance technologies is high and hence the measurements were reproducible. The results provide a rigorous basis to apply these measured properties in subsequent analyses to examine their association with skin tear occurrence at 6-months, which is described in Chapter 6.

Chapter 6

Individual Characteristics, Skin Characteristics and Skin Properties Associated with Skin Tears: Methodology and Results

6.1. Introduction

Having demonstrated the utility and reliability of non-invasive technologies to measure a range of morphological and physiological skin properties, the second key study objective was examined. A series of statistical analyses were undertaken to identify the effect of baseline variables for individual (including demographics) characteristic, skin characteristics, and morphological and physiological skin property variables on skin tear occurrence at 6-months, and to develop a predictive model for risk of skin tears. This chapter describes the methodology and presents the results.

6.2. Methodology

6.2.1. Datasets applied

The final dataset in this prospective cohort study comprised the measurements and observations of 173 (86.5%) of the original 200 participants, for whom complete data was available for all variables (including records of skin tear incidents) at both the initial and 6-month's assessment. Twenty-seven (13.5%) of the original 200 participants were lost to follow-up (25 participants were deceased during the 6-months and two participants declined to take part further in the study). The 173 reassessed participants comprised of 123 (71%) females and 50 (29%) males, with a combined mean age of 87.9 years ($SD \pm 6.8$).

The results for intra-rater reliability confirmed the conclusion from the pilot study that the measurement of skin properties, particularly on the extremities, was reliable and further analysis of skin properties associated with skin tears could proceed. Data derived from the measurement of

baseline individual (including demographics) characteristics, skin characteristics, and skin properties were examined to identify any statistically significant association with the skin tear occurrence at 6-months.

Due to the low number of skin tears at any one anatomical site direct comparison between specific skin tear sites was not possible. The skin tear data was therefore grouped across sites for analyses, to increase the statistical power of the study to investigate the second objective (Schold, 2011). The frequency of skin tears was the total number of skin tears that were recorded on any site of the body. In subsequent analyses, skin tear incidents refer to the total number of skin tears sustained by participants in the major prospective study.

6.2.2. Analysis sequence and order of presentation of results

The final dataset comprised a large array (> 390,000 cells) of high quality measurements and records for a broad range of variables, many of which had not previously been examined in studies examining the incidents of skin tears.

A flowchart is presented in Figure 6.1 to guide the reader through the statistical analysis process that was conducted for the major study. The overall sequence of analyses and the order of presentation in the following sections was structured to firstly identify those independent variables (individual characteristics, skin characteristics, and morphological and physiological skin properties) that were associated with the occurrence of skin tears at 6-months. Logistic regression was then used to examine the variables singly (univariable) and combined (multivariable) to develop a predictive model.

The results of the independent variable tests are presented separately for the categorical variables and then the continuous variables, to aid interpretation and maintain brevity. Further, because the literature review identified a range of limitations with previous studies examining the relationship between skin tears and individual characteristics and skin

characteristics (Section 2.5), the results are presented separately for those factors previously reported (in the literature) to be associated with skin tears, and for those 'additional' factors that are examined for the first time in this research.

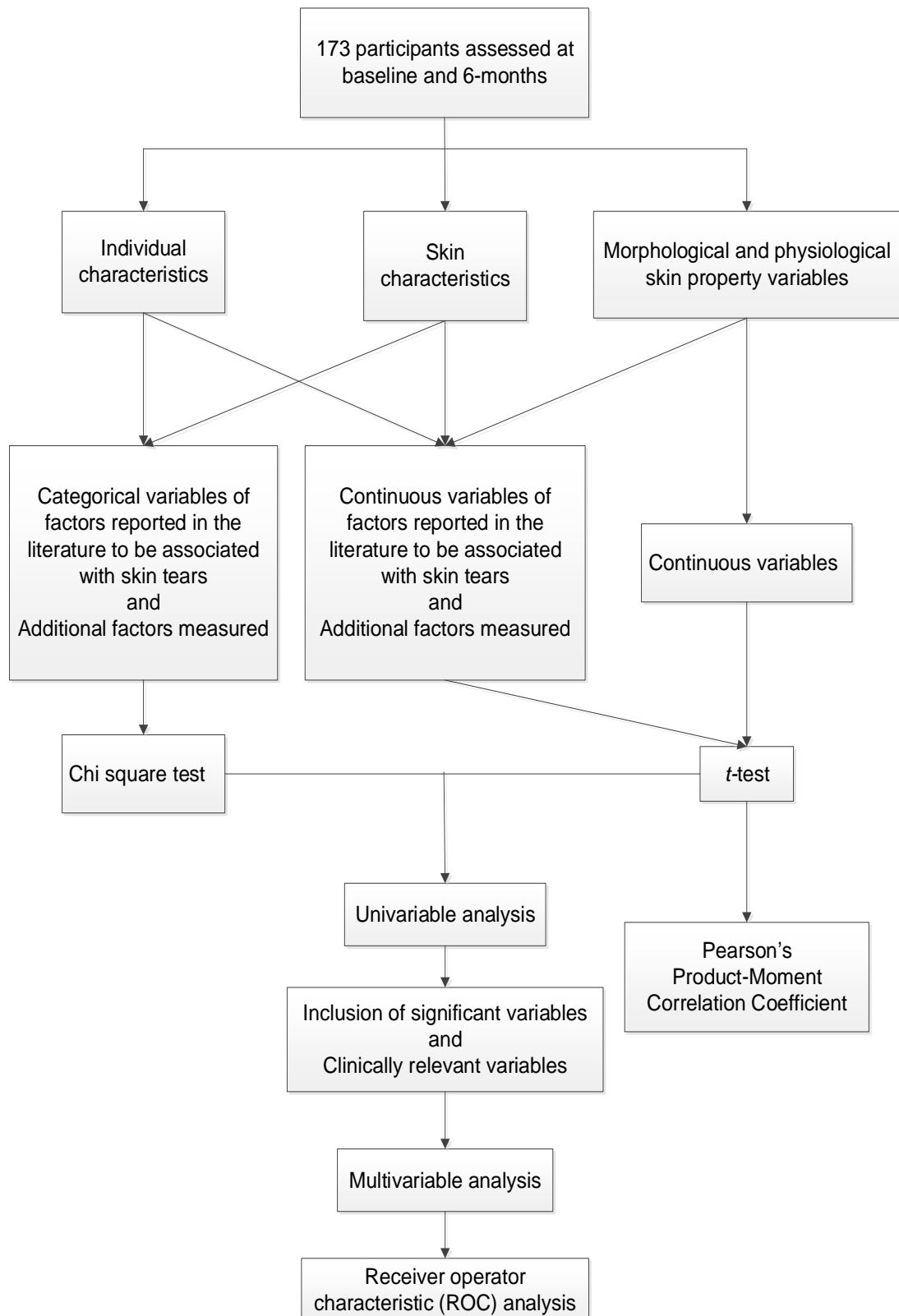


Figure 6.1. Flowchart of major study analysis process.

6.2.3. Statistical analyses and tests used to determine variables associated with skin tears

Descriptive statistics for individual characteristics and skin characteristics were calculated as the mean (M), standard deviation (SD) and median (inter-quartile range) for continuous variables, and frequency (percentage (%)) for categorical variables. The skin tear occurrence data, which recorded the number and location of skin tears, for all participants was obtained from the service providers integrated database 6-months after the initial assessment. Chi-squared (χ^2) tests were conducted to evaluate the frequency data for categorical variables and the occurrence of skin tears at 6-months (Page, 2017). Independent samples t -tests were used to compare continuous data between participants with skin tears and those without skin tears. Cohen's d statistic was used to estimate the effect size of independent samples t -tests: small (.20), medium (.30) and large (.50) effect (Kotrlík, Williams, & Jabor, 2011). The correlation between morphological and physiological skin properties was assessed using Pearson's Product-Moment Correlation Coefficient (r) with the alpha level set *a priori* at .05. The strength of association between the skin property values was interpreted using Hopkins (2002) benchmark scale: trivial (.00–.01), small (.01–.30), moderate (.30–.50), large (.50–.70), very large (.70–.90), and nearly perfect (.90–1.00).

Univariable logistic regression were conducted to test the association of a single explanatory variable to identify variables significantly associated with skin tears at 6-months, which were subsequently incorporated into multivariable analysis (Tsai, 2013). Multivariable logistic regression analysis was conducted to simultaneously test the associations between multiple variables with the risk of skin tears at 6-months, after taking in consideration other variables and possible confounders (Wakkee et al., 2014). Both significant variables, which were identified in the univariable analysis and additional variables that were considered to be clinically relevant were included in the multivariable logistic models. Univariable analysis may identify non-significant clinical variables that become significant in subsequent

multivariable analysis from an interactive effect of variables (Bursac, Gauss, Williams, & Hosmer, 2008).

The magnitude of the associations between each independent variable and the outcomes was expressed as an odds ratio (OR) with 95% confidence intervals (CIs) obtained by multivariable logistic regression. The OR measured the strength of association between a variable and the 6-month risk of skin tears (Szumilas, 2010).

A statistical model with a minimal number of independent variables that best predicted the risk of skin tears in participants was then developed. A ROC analysis, with a significance level of .05 was used to estimate individuals at risk or not at risk of skin tears. The ROC curve was computed using the sensitivity and specificity of the model in discrimination testing of residents with and without skin tears, and the corresponding AUC provide a graphic illustration of the performance of the statistical model (Florkowski, 2008). The AUC was used to interpret the probability that the skin tear model correctly identified participants with and without skin tears. The values for AUC ranged from 0–1 with values of about < 0.5 indicating no discrimination; 0.6 poor discrimination, 0.7 acceptable/good discrimination; 0.8 as very good discrimination; and 0.9 and above as excellent discrimination (Meyers, Gamst, & Guarino, 2013). It is ideal for a predictive model to have both high sensitivity and specificity, and consequently a high AUC.

6.3. Results

6.3.1. Frequency and location of skin tears sustained by participants.

Table 6.1 presents the number and relative proportion of the 173 participants who sustained a skin tear during the 6-month's period.

Table 6.1. Number of Skin tears at 6-Months and the Proportion of Participants

Number of skin tears	Participants n (%)	Total number of skin tears = number of participants x number of skin tears
1	26 (36.6)	26
2	19 (26.8)	38
3	8 (11.3)	24
4	6 (8.5)	24
5	3 (4.2)	15
6	1 (1.4)	6
7	2 (2.8)	14
8	1 (1.4)	8
9	1 (1.4)	9
12	1 (1.4)	12
13	1 (1.4)	13
15	1 (1.4)	15
20	1 (1.4)	20
Total	71 participants (100%)	224 skin tears

Note. n = number; % = percentage.

Over the 6-month's period the integrated data system recorded 41% (n = 71) participants as having a total of 224 skin tears. Exactly, 50% of all skin tears occurred in only 16.8% (n = 12) of participants, with participants sustaining between 5–20 skin tears over the 6-month assessment period. The remaining 50% of participants sustained between 1–4 skin tears.

The general location of the total number of skin tears by gender is presented in Table 6.2.

Table 6.2. General Location of Total Number of Skin Tears by Gender

Location	Location of skin tears by total sex and number of skin tears		
	Males (n = 31)	Females (n = 40)	Total
Right arm	33 (53.2)	29 (46.8)	62
Left arm	30 (44.1)	38 (55.9)	68
Right leg	20 (52.6)	18 (47.4)	38
Left leg	17 (43.6)	22 (56.4)	39
Head and face	9 (69.2)	4 (30.8)	13
Torso	1 (25.0)	3 (75.0)	4

Note. number (%).

At 6-months 41% (n = 71) of participants (31 males and 40 females) sustained one or more skin tears. In total, 62% of males and 32.5% of female participants sustained a skin tear. Regardless of gender, the majority of skin tears occurred on the upper extremities (58.0%), followed by the lower extremities (34.4%), head and face (5.8%), and torso (1.8%).

6.3.2. Factors previously reported to be associated with skin tears.

The initial analysis examined those factors commonly reported in the literature to be associated with skin tears, (LeBlanc & Baranoski, 2011; Newall et al., 2016; Sanada et al., 2015). A chi-square test was performed to test if there were significant difference between the baseline individual characteristics and skin characteristics in participants with and without skin tears at 6-months. A list of the documented individual and skin characteristics and the results of the chi-square analysis are presented in Table 6.3.

Table 6.3. Comparison Between Participants With and Without Skin Tears at 6-months Based on Personal Characteristics and Skin Characteristics Variables, as Reported in the Literature

	Participants with no skin tears (n = 102)	Participants with skin tears (n = 71)	
Variables	n (%)	n (%)	p-value
Individual characteristics			
Age: Mean (<i>SD</i>)	86.6 (7.2)	88.6 (6.1)	.049*
Sex			
Males	19 (38.0)	31 (62.0)	<.001**
Females	83 (67.5)	40 (32.5)	
Fitzpatrick skin type			
Type 1	7 (77.8)	2 (22.2)	.705
Type 2	30 (57.7)	22 (42.3)	
Type 3	45 (57.7)	33 (42.3)	
Type 4	20 (58.8)	14 (41.2)	
Nutrition			
Well nourished	80 (62.0)	49 (38.0)	.353
Resident obese	16 (48.5)	17 (51.5)	
Underweight and frail	6 (54.5)	5 (45.5)	
Assistance with nutrition			
Independent	10 (71.4)	4 (28.6)	.531
Requires supervision	72 (59.0)	50 (41.0)	
Needs physical assist	20 (54.1)	17 (45.9)	
Total number of medications: Mean (<i>SD</i>)	7.0 (3.4)	6.8 (3.5)	.678
Corticosteroid medications			
No	72 (60.5)	47 (39.5)	.540
Yes	30 (55.6)	24 (44.4)	
History skin tears 3-months			
No	87 (65.9)	45 (34.1)	.001**
Yes	15 (36.6)	26 (63.4)	
History skin tears 6-months			
No	78 (71.6)	31 (28.4)	<.001**
Yes	24 (37.5)	40 (62.5)	
History skin tears 12-months			
No	65 (77.4)	19 (22.6)	<.001**
Yes	37 (41.6)	52 (58.4)	
Braden Scale score (mean)	18.4 (3.7)	17.8 (3.3)	.296
Sensory impairment			
No	31 (68.9)	14 (31.1)	.115
Yes	71 (55.5)	57 (44.5)	
Mobility assistance			
No limitation	17 (70.8)	7 (29.2)	.384
Assist	66 (55.9)	52 (44.1)	
Bedfast or chair fast	19 (61.3)	12 (38.7)	

Ability to transfer			
Independent	55 (66.3)	28 (33.7)	.102
Assist	28 (48.3)	30 (51.7)	
Mechanical lifting device	19 (59.4)	13 (40.6)	
Ability to reposition self			
No	47 (51.6)	44 (48.4)	.039*
Yes	55 (67.1)	27 (32.9)	
Contractures			
No	98 (58.7)	69 (41.3)	.696
Yes	4 (66.7)	2 (33.3)	
Visual impairment			
Normal vision	12 (66.7)	6 (33.3)	.758
Blurred/cataracts/glaucoma	84 (58.3)	60 (41.7)	
Severe impairment	6 (54.6)	5 (45.5)	
Uses a visual aid			
No	15 (65.2)	8 (34.8)	.115
Yes	87 (58.0)	63 (42.0)	
PAS scale			
No impairment	5 (62.5)	3 (37.5)	.630
Mild impairment	34 (59.6)	23 (40.4)	
Moderate impairment	40 (63.5)	23 (36.5)	
Severe impairment	23 (51.1)	22 (48.9)	
PAS scale			
None or mild impairment			.829
Moderate-severe	39 (60.0)	26 (40.0)	
impairment	63 (58.3)	45 (41.7)	
Dementia			
No	43 (55.8)	34 (44.2)	.456
Yes	59 (61.5)	37 (38.5)	
Heart disease			
No	57 (57.0)	43 (43.0)	.540
Yes	45 (61.6)	28 (38.4)	
Respiratory disease			
No	94 (61.8)	58 (38.2)	.038*
Yes	8 (38.1)	13 (61.9)	
ADL score (mean)	79.7 (17.2)	80.7 (17.4)	.718
ADL scale			
Low	9 (56.3)	7 (43.8)	.266
Medium	47 (66.2)	24 (33.8)	
High	46 (53.5)	40 (46.5)	
History of falls 1-months			
No	81 (63.8)	46 (36.2)	.032*
Yes	21 (45.7)	25 (54.3)	
History of falls 3-months			
No	72 (72.0)	28 (28.0)	<.001**
Yes	30 (41.1)	43 (58.9)	
History of falls 6-months			
No	55 (75.3)	18 (24.7)	<.001**
Yes	47 (47.0)	53 (53.0)	
Type of skin cleanser used			
Soap	30 (50.8)	29 (49.2)	.083
pH neutral cleanser	71 (64.5)	39 (35.5)	

Incontinence/continence			
Continent	7 (46.7)	8 (53.3)	.259
Urinary	37 (67.3)	18 (32.7)	
Faecal	4 (80.0)	1 (20)	
Urinary and faecal	54 (55.1)	44 (44.9)	
TBPI right leg score	.8 (.2)	.7 (.3)	.128
TBPI left leg score	.7 (.2)	.7 (.2)	.373
Venous PPG right leg			
> 20 seconds	11 (47.8)	12 (52.2)	.196
< 20 seconds	68 (62.4)	41 (37.6)	
Venous PPG left leg			
> 20 seconds	10 (47.6)	11 (52.4)	.244
< 20 seconds	68 (61.3)	43 (38.7)	
Skin characteristics			
Vascular skin lesion			
Nil	54 (83.1)	11 (16.9)	<.001**
Purpura	29 (45.3)	35 (54.7)	
Purpura and ecchymosis	19 (43.2)	25 (56.8)	
Purpura ≤ 20 mm			
No	54 (83.1)	11 (16.9)	<.001**
Yes	48 (44.4)	60 (55.6)	
Ecchymosis ≥ 20 mm			
No	83 (64.3)	46 (35.7)	.014*
Yes	19 (43.2)	25 (56.8)	
Bruising			
No	99 (58.9)	69 (41.1)	.962
Yes	3 (60.0)	2 (40.0)	
Haematoma			
No	102 (59.0)	71 (41.0)	–
Yes	0.0 (0)	0.0 (0)	
Upper limb oedema			
No	102 (59.6)	69 (40.4)	.852
Yes	0.0 (0)	2 (100)	
Lower limb oedema			
No	56 (58.3)	40 (41.7)	.345
Yes	46 (59.7)	31 (40.3)	

Note. n = number; % = percentage; SD = standard deviation, *p*-value from chi-square test for categorical variables or *t*-test for continuous variables; PAS = psychogeriatric assessment scale; ADL = activities of daily living; TBPI = toe brachial pressure index; PPG = photoplethysmography. An asterisk (*) indicates a statistically significant difference, * = *p* < 0.05; ** = *p* < 0.01.

The chi-square analysis of baseline individual characteristics (Table 6.3) identified the following variables to be significantly associated with the skin tear occurrence at 6-months: gender; a history of skin tears in the previous 3-months, 6-months and 12-months; respiratory disease; and a history of falls

in the previous 1-month, 3-months and 6-months. The ability to reposition self was identified to be significantly associated with not sustaining a skin tear. Two skin characteristics were found to be significantly associated with skin tears at 6-months: purpura and ecchymosis.

A broad range of variables that were commonly reported in the literature to be associated with skin tears were found not to be significantly associated with the skin tear occurrence at 6-months in participants of this prospective study. These variables included: ability to reposition self; ethnicity; altered sensory status; bruising; cardiac problems; cognitive impairment; contractures; corticosteroid therapy; decreased Braden Scale score; dependency for ADL; haematoma; immobility; inadequate nutritional intake; incontinence; neuropathy; oedema; polypharmacy; use of skin cleansers; transferring residents; use of an assistive device; vascular problems; and visual impairment. Despite a reported link between Caucasian ethnicity and skin tears, the present study could not evaluate this factor due to the relative homogeneity of the ethnicity of the sample in this study. Similarly, in this sample of residents no association was evident between Fitzpatrick skin types and skin tears, even though participants were classified as having Fitzpatrick skin types that ranged between I–IV.

6.3.3. Additional individual and skin characteristics.

In addition to those factors reported in the literature to be associated with skin tears, a broad range of additional individual characteristics and skin characteristics were measured in this study. A chi-square test was performed to test for any significant association between these additional baseline individual characteristics and skin characteristics in participants with and without skin tears at 6-months. The results of this analysis are presented in Table 6.4.

Table 6.4. Comparison Between Participants With and Without Skin Tears at 6-months Based on Additional Personal Characteristics and Skin Characteristics Variables

Variables	No skin tears (n = 102)	Skin tears (n = 71)	p-value
Individual characteristics			
Place of birth			
Oceanian	66 (55.5)	53 (44.5)	.577
North-West European	26 (68.4)	12 (31.6)	
Southern/Eastern European	4 (57.1)	3 (42.9)	
South-East Asian	1 (50.0)	1 (50.0)	
North-East Asian	1 (100)	0 (0.0)	
Southern and Central Asian	0 (0.0)	1 (100)	
Central Americans	2 (66.7)	1 (33.3)	
Sub-Saharan African	2 (100)	0 (0.0)	
History of smoking			
Lifelong non-smoker	62 (64.6)	34 (35.4)	.229
Ex-smoker	37 (55.2)	30 (44.8)	
Principle work environment			
Mix indoor/outdoor work	98 (65.3)	52 (34.7)	<.001**
Primarily worked outdoors	4 (17.4)	19 (82.6)	
Activity level			
Walks frequently	22 (64.5)	27 (35.5)	.096
Walks occasionally	31 (48.4)	33 (51.6)	
Bedfast and chairfast	22 (66.7)	11 (33.3)	
Cornell scale for depression			
0-8	35 (67.3)	17 (32.7)	.148
9-13	35 (63.6)	20 (36.4)	
14-18	22 (51.2)	21 (48.8)	
19-38	10 (43.5)	13 (56.5)	
Behavioural needs scale			
Low	21 (61.8)	13 (38.2)	.083
Medium	17 (43.6)	22 (56.4)	
High	64 (64.0)	36 (36.0)	
Agitation			
None or occasional issue	49 (68.1)	23 (31.9)	.040*
Moderate to severe issue	53 (52.5)	48 (47.5)	
Sleep patterns			
Normal sleep patterns	29 (69.0)	13 (31.0)	.163
Sleep occasionally disturbed	53 (53.0)	47 (47.0)	
Severe sleep disturbance	20 (64.5)	11 (35.5)	
Allergies present			
No	55 (55.0)	45 (45.0)	.215
Yes	47 (64.4)	26 (35.6)	

Falls risk category			
Medium (11-20)	61 (73.5)	22 (26.5)	<.001**
High (21-39)	41 (45.6)	49 (54.4)	
Atrial fibrillation			
No	85 (57.8)	62 (42.2)	.470
Yes	17 (65.4)	9 (34.6)	
Angina			
No	95 (59.0)	66 (41.0)	.964
Yes	7 (58.3)	5 (41.7)	
Myocardial infarction			
No	93 (58.9)	65 (41.1)	.932
Yes	9 (60.0)	6 (40.0)	
Ischaemic heart disease			
No	93 (60.4)	61 (39.6)	.276
Yes	9 (47.4)	10 (52.6)	
Congested cardiac failure			
No	96 (60.0)	64 (40.0)	.329
Yes	6 (46.2)	7 (53.8)	
Diabetes			
No	67 (54.0)	57 (46.0)	.110
Type 1	2 (66.7)	1 (33.3)	
Type 2	33 (71.7)	13 (28.3)	
Hypothyroidism			
No	83 (57.6)	61 (42.4)	.431
Yes	19 (65.5)	10 (34.5)	
Asthma			
No	98 (60.1)	65 (39.9)	.209
Yes	4 (40.0)	6 (60.0)	
COPD			
No	93 (62.0)	57 (38.0)	.038*
Yes	9 (39.1)	14 (60.9)	
Renal disease			
No	92 (59.4)	63 (40.6)	.756
Yes	10 (55.6)	8 (44.4)	
Paralysis			
No	95 (57.2)	71 (42.8)	.024*
Yes	7 (100)	0 (0.0)	
CVA			
No	84 (59.6)	57 (40.4)	.730
Yes	18 (56.3)	14 (43.8)	
Hypertension			
No	39 (56.5)	30 (43.5)	.595
Yes	63 (60.6)	41 (39.4)	
Cancer			
No	88 (61.1)	56 (38.9)	.200
Yes	14 (48.3)	15 (51.7)	
Osteoarthritis			
No	57 (60.6)	37 (39.4)	.624
Yes	45 (57.0)	34 (43.0)	

Rheumatoid arthritis			
No	98 (58.7)	69 (41.3)	.696
Yes	4 (66.7)	2 (33.3)	
Osteoporosis			
No	49 (59.0)	34 (41.0)	.984
Yes	53 (58.9)	37 (41.1)	
Parkinson disease			
No	95 (59.7)	64 (40.3)	.477
Yes	7 (50.0)	7 (50.0)	
Anxiety			
No	71 (55.0)	58 (45.0)	.073
Yes	31 (70.5)	13 (29.5)	
Anti-inflammatories			
No	91 (58.3)	65 (41.7)	.612
Yes	11 (64.7)	6 (35.3)	
Diuretics			
No	66 (61.1)	42 (38.9)	.458
Yes	36 (55.4)	29 (44.6)	
Antipsychotics			
No	81 (59.1)	56 (40.9)	.932
Yes	21 (58.3)	15 (41.7)	
Antidepressants			
No	50 (57.5)	37 (42.5)	.689
Yes	52 (60.5)	34 (39.5)	
Antihypertensives			
No	50 (61.0)	32 (39.0)	.609
Yes	52 (57.1)	39 (42.9)	
Oral corticosteroids			
No	97 (59.5)	66 (40.5)	.553
Yes	5 (50.0)	5 (50.0)	
Topical corticosteroids			
No	81 (60.0)	54 (40.0)	.600
Yes	21 (55.3)	17 (44.7)	
Inhalation corticosteroids			
No	95 (59.4)	65 (40.6)	.697
Yes	7 (53.8)	6 (46.2)	
Anticoagulants			
No	95 (57.9)	69 (42.1)	.239
Yes	7(77.8)	2 (22.2)	
Antiplatelets			
No	64 (62.1)	39 (37.9)	.303
Yes	38 (54.3)	32 (45.7)	
Opioids			
No	77 (58.8)	54 (41.2)	.932
Yes	25 (59.5)	17 (40.5)	
Sedative			
No	83 (57.6)	61 (42.4)	.431
Yes	19 (65.5)	10 (34.5)	

Moisturiser used			
No	32 (56.1)	25 (43.9)	.597
Yes	70 (60.3)	46 (39.7)	
Skin characteristics			
Purpura ≤ 20 mm forearms			
No	63 (76.8)	19 (23.2)	<.001**
Yes	39 (42.9)	52 (57.1)	
Purpura ≤ 20 mm legs			
No	74 (68.5)	34 (31.5)	.001**
Yes	28 (43.1)	37 (56.9)	
Ecchymosis ≥ 20 mm forearms			
No	92 (62.2)	56 (37.8)	.037*
Yes	10 (40)	15 (60.0)	
Ecchymosis ≥ 20 mm legs			
No	89 (61.8)	55 (38.2)	.090
Yes	13 (44.8)	16 (55.2)	
Presence scar tissue			
No	41 (73.2)	15 (26.8)	.008**
Yes	61 (52.1)	56 (47.9)	
Dermatological skin condition			
No	99 (59.3)	68 (40.7)	.831
Yes	3 (50.0)	3 (50.0)	
Density hair arms			
Light	86 (65.6)	45 (34.4)	.005**
Moderate	14 (41.2)	20 (58.8)	
Heavy	2 (25.0)	6 (75.0)	
Density hair legs			
Light	89 (57.8)	65 (42.2)	.374
Moderate	13 (68.4)	6 (31.6)	
Lax skin			
No	3 (30.0)	7 (70.0)	.055
Yes	99 (60.7)	64 (39.3)	
Fine wrinkles			
Mild	41 (45.1)	50 (54.9)	<.001**
Moderate/severe	61 (74.4)	21 (25.6)	
Coarse wrinkles			
No	69 (62.2)	42 (37.8)	.374
Yes	33 (53.2)	29 (46.8)	
Lentigines			
No	62 (58.5)	44 (41.5)	.082
Yes	40 (59.7)	27 (40.3)	
Uneven pigmentation			
No	44 (71.0)	18 (29.0)	.016*
Yes	58 (52.3)	53 (47.7)	
Yellowness			
No	101 (59.8)	68 (40.2)	.162
Yes	1 (25.0)	3 (75.0)	

Permanent redness			
No	80 (63.0)	47 (37.0)	.073
Yes	22 (47.8)	24 (52.2)	
Elastosis			
No	72 (70.6)	30 (29.4)	<.001**
Yes	30 (42.3)	41 (57.7)	
Pseudoscars			
No	98 (60.9)	63 (39.1)	.061
Yes	4 (33.3)	8 (66.7)	
History of actinic keratosis			
No	63 (68.5)	29 (31.5)	.007**
Yes	39 (48.1)	42 (51.9)	
History of a malignant skin lesion			
No	76 (62.3)	46 (37.7)	.168
Yes	26 (51.0)	25 (49.0)	
Cutis rhomboidalis nuchae			
No	77 (63.1)	45 (36.9)	.086
Yes	25 (49.0)	26 (51.0)	

Note. n = number (%); COPD = chronic obstructive pulmonary disease; CVA = cerebral vascular accident; Chi-squared test was use to evaluate associations and the p-values are presented. An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

Additional baseline individual characteristics that were significantly associated with skin tears at 6-months in this study sample included the historical principal work environment, falls risk category, chronic obstructive pulmonary disease (COPD), agitation, and paralysis.

Additional skin characteristics identified to be significantly associated with skin tears at 6-months included: purpura of the forearms; purpura of the lower legs; ecchymosis of the forearms; density of hair across the forearms; clinical manifestations of elastosis, scar tissue across the extremities, fine wrinkles, uneven pigmentation and history of actinic keratosis.

6.3.4. General continuous variables morphological and physiological skin property variables.

An independent samples two-tailed *t*-test was used to evaluate the difference in mean baseline continuous variables and skin property measurements between participants with and without skin tears at 6-months. A statistically significant difference was identified between participants with

skin tears and participants without skin tears for the following baseline variables: age; TEWL upper extremities; TEWL lower extremities; pH upper extremities; pH lower extremities; pH abdomen; SLEB lower extremities; venous PPG right leg; and height. No significant difference ($p > 0.05$) was found between skin hydration, skin thickness, skin elasticity properties (distensibility, retraction and VE) and transepidermal skin proteins between participants with and without skin tears at 6-months (Table 6.5).

Table 6.5. Independent-Samples t-test Comparing the Means of Continuous Baseline Variables with 6-Months Incidents of Skin Tears

	No skin tears (n = 102)		Skin tears (n = 71)		
Variables	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>p</i> -value
Individual characteristics					
Precise age	86.55	7.16	88.63	6.12	.049*
Number of days in facility	1019.37	998.41	825.20	816.56	.178
Number of years living in Australia	74.33	21.66	80.10	19.89	.077
Weight in kilograms	65.08	15.06	69.56	17.10	.070
Height in centimetres	160.88	8.10	164.01	9.62	.022*
Body mass index	25.40	5.01	25.79	5.82	.635
ADL precise score	25.40	5.01	80.68	17.37	.718
Number of chronic diseases	3.60	1.59	3.65	1.41	.832
Braden Scale score	18.39	3.73	17.82	3.28	.296
Number of medications	6.98	3.36	6.76	3.51	.678
Skin properties					
Mean melanin	29.83	4.26	29.93	3.40	.866
Mean TEWL upper extremities	7.34	2.59	8.60	3.11	.004**
Mean TEWL lower extremities	5.05	1.41	5.56	1.72	.035*
Mean TEWL abdomen	4.94	1.62	5.29	1.54	.160
Mean hydration upper extremities	81.96	30.21	72.71	32.95	.058
Mean hydration lower extremities	89.29	33.64	82.55	37.32	.217
Mean hydration abdomen	135.53	47.07	129.93	33.46	.390
Mean pH upper extremities	5.63	0.51	5.84	0.45	.004**
Mean pH lower extremities	5.70	0.48	5.88	0.46	.014*
Mean pH abdomen	5.89	0.49	6.03	0.40	.046*
Mean SLEB upper extremities	282.36	71.51	300.96	98.17	.151
Mean SLEB lower extremities	133.71	70.70	161.49	69.04	.011*
Mean SLEB abdomen	56.80	84.07	69.59	96.68	.356
Mean skin thickness upper extremities	821.57	172.32	829.59	193.03	.775

Mean skin thickness lower extremities	1106.92	253.20	1075.12	261.22	.424
Mean skin thickness abdomen	1175.65	269.40	1194.45	265.75	.651
Mean skin intensity score upper extremities	44.52	10.76	44.18	12.24	.847
Mean skin intensity score lower extremities	45.87	14.54	46.80	14.93	.681
Mean skin intensity score abdomen	51.15	22.59	47.48	20.78	.278
Mean VE upper extremities	4.15	1.58	4.27	1.57	.632
Mean VE lower extremities	2.35	1.08	2.60	1.32	.177
Mean VE abdomen	3.06	1.93	3.29	2.12	.475
Mean distensibility upper extremities	13.71	2.47	13.46	2.79	.531
Mean distensibility lower extremities	16.63	1.80	16.44	1.94	.515
Mean distensibility abdomen	6.88	2.80	7.14	2.69	.534
Mean retraction upper extremities	5.12	2.96	5.57	4.22	.413
Mean retraction lower extremities	3.92	2.54	4.00	2.35	.823
Mean retraction abdomen	955.08	1152.20	1017.53	1167.52	.751
Mean venous PPG right leg	11.59	7.38	14.87	8.40	.020*
Mean venous PPG left leg	11.58	6.86	12.61	7.82	.434
Mean TBPI right foot	0.75	0.24	0.69	0.29	.128
Mean TBPI left foot	0.73	0.20	0.70	0.22	.373

Transepidermal skin proteins

Mean type IV collagen pixels' forearm	77507.74	23725.32	79122.42	22546.74	.654
Mean type IV collagen mean intensity forearm	23.98	17.77	24.12	17.77	.959
Mean type IV collagen SD intensity forearm	10.26	7.23	10.69	7.75	.711
Mean type IV collagen pixels' leg	78411.72	25320.22	79508.45	23653.88	.774
Mean type IV collagen mean intensity leg	24.26	17.54	22.66	21.60	.591
Mean type IV collagen SD intensity leg	11.22	10.50	9.21	5.30	.138
Mean MMP-2 pixels' forearm	79643.03	24854.23	78105.45	23285.42	.682

Mean MMP-2 mean intensity forearm	22.14	26.74	18.85	26.82	.428
Mean MMP-2 <i>SD</i> intensity forearm	12.73	11.90	11.09	10.13	.346
Mean MMP-2 pixels' leg	79869.93	24575.70	80170.42	23630.24	.936
Mean MMP-2 mean intensity leg	18.44	19.39	16.57	26.13	.591
Mean MMP-2 <i>SD</i> intensity leg	12.50	13.31	9.59	8.27	.078
Mean TNF-alpha forearm	80480.35	25637.22	79529.93	23089.06	.803
Mean TNF-alpha mean intensity forearm	63.05	74.31	69.64	79.47	.578
Mean TNF-alpha <i>SD</i> intensity forearm	15.68	13.09	17.30	11.63	.403
Mean TNF-alpha pixels' leg	80317.74	25328.80	81605.52	24735.47	.740
Mean TNF-alpha mean intensity leg	63.32	77.48	71.87	79.69	.481
Mean TNF-alpha <i>SD</i> intensity leg	14.96	9.93	17.39	11.94	.148

Note. *M* = mean; *SD* = standard deviation; *t* = *t*-test; ADL = activities of daily living; TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band; VE = viscoelasticity; PPG = photoplethysmography; TEBI = toe brachial pressure index. An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

The mean age of participants with skin tears was significantly older than participants without skin tears (Table 6.5). Participants with skin tears had a significantly higher mean TEWL of the dorsal forearm and the lower extremities than participants without skin tears. Likewise, participants with skin tears had a significantly higher mean pH of the dorsal forearm and lower extremities than participants without skin tears. Participants with skin tears had a significantly wider SLEB of the lower extremities than participants without skin tears. Participants with skin tears had a significantly slower right venous mean PPG compared to participants without skin tears. Participants with skin tears were significantly taller than participants without skin tears.

6.3.5. Combined reported and additional characteristics.

Univariable and multivariable logistic regression was used to estimate the odd ratios for the complete set of baseline variables (combined reported and

additional characteristics), and the risk of skin tears at 6-months. The dependent variable (skin tears) was categorised as 0 = no skin tears and 1 = skin tears. The findings from the univariable and multivariable analyses are reported in Table 6.6. Univariable analysis identified 34 variables that were potential predictors of skin tears. Subsequent multivariable analysis identified eight variables that were significantly and independently associated with skin tears at 6-months. These variables comprised of three individual characteristics (gender, history of skin tears at 12-months, history of falls in previous 3-months); two skin characteristics (purpura all sites; cutaneous elastosis); and three skin properties that were significantly associated with skin tears including: increased TEWL of the forearms, increased mean pH of the forearms, and the presence of SLEB across the bilateral lower extremities.

Table 6.6. Results of Univariable and Multivariable Analysis of Baseline Variables Associated with Skin Tears at 6-Months

Variables	Skin tear incidents at 6-months (Univariable)	Skin tear incidents at 6-months (Multivariable)
	OR (95% CI)	OR (95% CI)
Individual characteristics		
Sex (males vs. females)	3.39 (1.71–6.71) (p < .001)	3.08 (1.22–7.77) (p = .017)
Principle work environment (mix indoor / outdoor vs. primarily working outdoors)	.20 (.05–.79) (p = .021)	
History skin tears in previous 3-months (yes vs. no)	3.35 (1.61–6.96) (p = .001)	
History skin tears in previous 6-months (yes vs. no)	4.19 (2.18–8.08) (p < .001)	
History skin tears in previous 12-months (yes vs. no)	4.81 (2.48–9.33) (p < .001)	3.82 (1.64–8.90) (p = .002)
Falls risk category (medium vs. high)	3.31 (1.75–6.29) (p < .001)	
History of falls in previous 1-months (yes vs. no)	2.10 (1.06–4.15) (p = .034)	
History of falls in previous 3-months (yes vs. no)	3.69 (1.95–6.98) (p < .001)	3.37 (1.54–7.41) (p = .002)
History of falls in previous 6-months (yes vs. no)	3.45 (1.78–6.68) (p < .001)	
Respiratory disease (yes vs. no)	2.63 (1.03–6.74) (p = .043)	
COPD (yes vs. no)	2.54 (1.03–6.24) (p = .043)	
Agitation (moderate / severe vs. nil / occasionally)	1.93 (1.03–3.63) (p = .041)	
Ability to reposition self (yes vs. no)	1.91 (1.03–3.54) (p = .040)	
Skin characteristics		
Density hair arms		
Moderate vs. light	2.73 (1.26–5.91)	
Heavy vs. light	5.73 (1.11–29.57) (p = .007)	
Purpura/ecchymosis		
Purpura vs. none	5.93 (2.63–13.37)	
Purpura/ecchymosis vs. none	6.46 (2.68–15.59) (p < .005)	
Purpura all sites (yes vs. no)	6.14 (2.90–13.01) (p < .001)	3.64 (1.42–9.35) (p = .007)

Purpura arms (yes vs. no)	4.42 (2.29–8.55)	
	(p < .001)	
Purpura (< 20 mm) legs (yes vs. no)	2.88 (1.52–5.44)	
	(p = .001)	
Ecchymosis all sites (yes vs. no)	2.37 (1.18–4.77)	
	(p = .015)	
Ecchymosis arms (yes vs. no)	2.46 (1.04–5.86)	
	(p = .041)	
Purpura or ecchymosis		
Purpura vs. none	5.93 (2.63–13.37)	
Ecchymosis vs. none	6.46 (2.68–15.59)	
	(p < .001)	
Scar tissue (yes vs. no)	2.51 (1.25–5.02)	
	(p = .009)	
Uneven pigmentation (yes vs. no)	2.23 (1.15–4.33)	
	(p = .017)	
Fine wrinkles (mild vs. moderate / severe)	.28 (.15–.54)	
	(p < .001)	
Cutaneous elastosis (yes vs. no)	3.28 (1.74–6.19)	3.19 (1.38–7.38)
	(p < .001)	(p = .007)
Actinic keratosis (yes vs. no)	2.34 (1.26–4.35)	
	(p = .007)	
Malignant skin lesion (yes vs. no)	2.44 (1.30–4.59)	
	(p = .006)	

**Skin properties and continuous variables
(OR based on a unit change in these variables)**

Mean TEWL bilateral forearms	1.17 (1.05–1.31)	1.14 (1.01–1.28)
	(p = .006)	(p = .033)
Mean TEWL bilateral legs	1.24 (1.01–1.51)	
	(p = .038)	
Mean pH bilateral forearms	2.57 (1.32–5.01)	2.56 (1.26–5.21)
	(p = .006)	(p = .010)
Mean pH bilateral legs	2.34 (1.17–4.67)	
	(p = .016)	
Mean SLEB bilateral forearm	1.00 (1.00–1.01)	
Mean SLEB bilateral legs	1.01 (1.00–1.01)	1.00 (1.00–1.01)
	(p = .006)	(p = .028)
Height	1.04 (1.01–1.08)	
	(p = .024)	

Note. OR = odds ratio; CI = confidence interval; p = p-value; TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band; vs = versus.

6.3.6. Skin tear model.

Stepwise method (forward selection) of nominated variables was applied in the multivariable regression analysis. Identified variables that could

potentially confound the analysis were accounted for in the statistical model by adjusting for other explanatory variables — age, gender, history of skin tears, history of falls and BMI. These variables were considered as covariates and adjusted for in order to increase the predictive power of the analysis (Wilson & Lorenz, 2015). Estimated effects of a variable are recognised to impact on the inclusion or exclusion of other variables and influence the outcome of the statistical model (Blettner, Krahn, & Schlattman, 2014).

The statistical skin tear model that provided the best explanation of the data identified five variables (three individual and two skin characteristics) to be statistically significant predictors of skin tears at 6-months. The results of this analysis are presented in Table 6.7.

Table 6.7. Results of the Multivariable Analysis (95% CI) of Baseline Variables and the 6-Months Incidents of Skin Tears in Residents (n=173)

Descriptive variables	Skin tear incidents at 6-months	
	OR (95% CI)	p-value
Gender		
Females	1	
Males	3.08 (1.22–7.77)	.017
History of skin tears previous 12-months		
No	1	
Yes	3.82 (1.64–8.90)	.002
History falls in previous 3-months		
No	1	
Yes	3.37 (1.54–7.41)	.002
Clinical elastosis		
No	1	
Yes	3.19 (1.38–7.38)	.007
Purpura		
No	1	
Yes	3.64 (1.42–9.35)	.007

Note. OR = odds ratio; CI = confidence interval.

The individual and skin characteristics that were identified to be significantly associated with skin tears at 6-months included: male gender, history of skin tears in the previous 12-months, history of falls within the

preceding 3-months, cutaneous manifestations of elastosis and purpura. The analysis did not identify any morphological or physiological skin property that significantly predicted the risk of skin tears at 6-months. However, some of these skin properties predicted the risk of elastosis and purpura, which are already included in the model (see Sections 6.3.7 and 6.3.8).

A ROC curve was generated to assess the performance of the skin tear model (Figure 6.2).

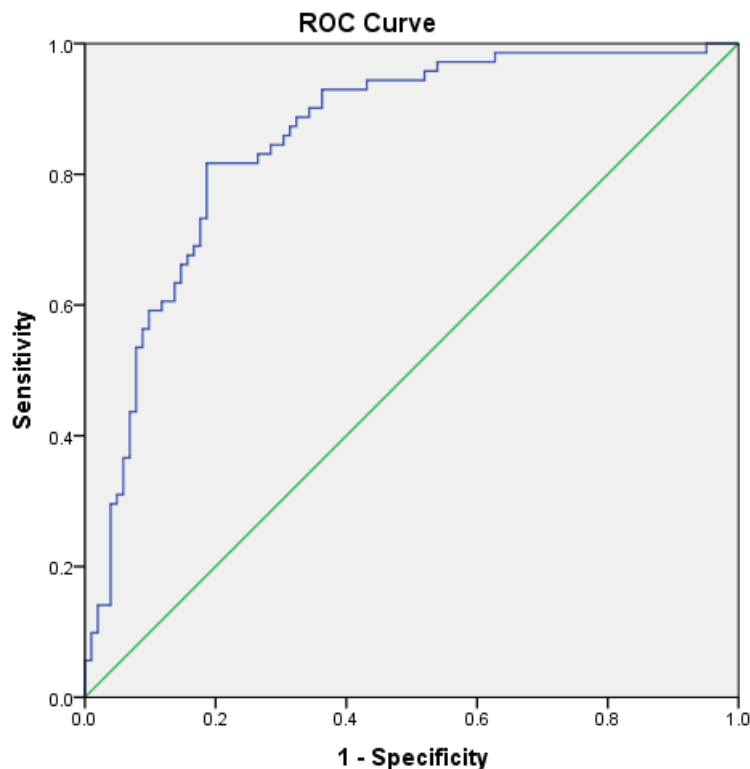


Figure 6.2. Receiver operating characteristic (ROC) curve showing the sensitivity and 1-specificity of the model for various cut-off values to determine individuals at risk of skin tears.

The model yielded an AUC of .854, which indicates the skin tear model provides 'very good discrimination' to correctly classify participants with and without skin tears (Meyers et al., 2013). The skin tear model correctly predicted 81.7% (sensitivity) of participants with skin tears and 81.4% (specificity) of participants without skin tears. To better understand the inclusion of the two clinical characteristics (cutaneous manifestations of

elastosis and purpura) into the model, and the associated risk of skin tears further analysis was conducted.

6.3.7. Cutaneous manifestations of elastosis.

Cutaneous manifestation of elastosis referred to exposed skin that displayed a coarse, thickened, scaly, dry, and rigid texture compared to adjacent non-exposed skin sites. Clinical manifestation of elastosis was a significant and independent risk factor for skin tears (Table 6.7). A chi-square test was conducted to test if there was any significant difference between pertinent baseline individual and skin characteristics and participants with and without elastosis. The result of this analysis is presented in Table 6.8.

Clinical manifestations of elastosis were identified in 66% of male and 30.9% of female participants. Individual characteristics found to be significantly associated with elastosis including gender, a history of smoking, activity level, ability to transfer, myocardial infarction, cancer, osteoporosis, and anxiety. However, except for gender and a history of smoking, the remaining individual variables appeared to be biologically implausible and made little or no clinical sense in relation to the cutaneous manifestations of elastosis. Skin characteristics that were identified to be significantly associated with the cutaneous manifestations of elastosis included: coarse wrinkles; lentigines; uneven skin pigmentation of the forearms; a history of AK; and cutis rhomboidalis nuchae.

Table 6.8. Chi-square of Baseline Variables Associated with Elastosis

Variables	No elastosis (n = 102)	Elastosis (n = 71)	p-value
Individual characteristics			
Gender			
Females	85 (69.1)	38 (30.9)	<.001**
Males	17 (34.0)	33 (66.0)	
History of smoking			
Lifelong non-smoker	67 (69.8)	29 (30.2)	.003**
Ex-smoker	31 (46.3)	36 (53.7)	
Place of birth			
Oceanian	64 (53.8)	55 (46.2)	.132
North-West European	28 (73.7)	10 (26.3)	
Southern and Eastern European	4 (57.1)	3 (42.9)	
South-East Asian	1 (50.0)	1 (50.0)	
North-East Asian	1 (100)	0 (0.0)	
Southern and Central Asian	1 (100)	0 (0.0)	
People of the Central Americans	3 (100)	0 (0.0)	
Sub-Saharan African	0 (0.0)	2 (100)	
Previous occupation			
Managers and administrators	1 (14.3)	6 (85.7)	.091
Professionals	25 (71.4)	10 (28.6)	
Associate professionals	4 (40.0)	6 (60.0)	
Trades and related workers	6 (46.2)	7 (53.8)	
Advanced clerical and service	4 (66.7)	2 (33.3)	
Inter clerical, sales and service	10 (71.4)	4 (28.6)	
Production and transport workers	5 (71.4)	2 (28.6)	
Elementary sales and service	39 (61.9)	24 (38.1)	
Labourers	8 (44.4)	10 (55.6)	
Principle work environment			
Mix indoor/outdoor work	92 (61.3)	58 (38.7)	.105
Primarily worked outdoors	10 (43.5)	13 (56.5)	
Mobility impairment			
No	22 (53.7)	19 (46.3)	.430
Yes	80 (60.6)	52 (39.4)	
Activity level			
Walks frequently	38 (50.0)	38 (50.0)	.019*
Walks occasionally	38 (59.4)	26 (40.6)	
Bedfast and chairfast	26 (78.8)	7 (21.2)	
Mobility			
Independent	12 (52.2)	11 (47.8)	.646
Supervision	39 (62.9)	23 (37.1)	
Physical assistance	51 (58.0)	37 (42.0)	
Mobility assistance			
No limitation	13 (54.2)	11 (45.8)	.161
Assist	66 (55.9)	52 (44.1)	
Bedfast or chair fast	23 (74.2)	8 (25.8)	
Ability to transfer			
Independent	50 (60.2)	33 (39.8)	.045*
Assist	28 (48.3)	30 (51.7)	
Mechanical lifting device	24 (75.0)	8 (25.0)	

Ability to reposition self			
No	49 (53.8)	42 (46.2)	.150
Yes	53 (64.6)	29 (35.4)	
Contractures			
No	97 (58.1)	70 (41.9)	.217
Yes	5 (83.3)	1 (16.7)	
Visual impairment			
Normal vision	11 (61.1)	7 (38.9)	.607
Blurred/cataracts/glaucoma	83 (57.6)	61 (42.4)	
Severe impairment	8 (72.7)	3 (27.3)	
Uses a visual aid			
No	15 (65.2)	8 (34.8)	.512
Yes	87 (58.0)	63 (42.0)	
Sensory impairment			
No	88 (57.1)	66 (42.9)	.167
Yes	14 (73.7)	5 (26.3)	
Incontinence/continence			
Continent	6 (40.0)	9 (60.0)	.371
Urinary	31 (56.4)	24 (43.6)	
Faecal	3 (60.0)	2 (40.0)	
Urinary and faecal	62 (63.3)	36 (36.7)	
Type of skin cleanser used			
Soap	60 (54.5)	50 (45.5)	.146
pH neutral cleanser	39 (66.1)	20 (33.9)	
Moisturiser used			
No	30 (52.6)	27 (47.4)	.236
Yes	72 (62.1)	44 (37.9)	
PAS scale			
No impairment	6 (75.0)	2 (25.0)	.062
Mild impairment	26 (45.6)	31 (54.4)	
Moderate impairment	43 (68.3)	20 (31.7)	
Severe impairment	27 (60.0)	18 (40.0)	
ADL scale			
Low	9 (56.3)	7 (43.8)	.797
Medium	44 (62.0)	27 (38.0)	
High	49 (57.0)	37 (43.0)	
History skin tears 3-months			
No	81 (61.4)	51 (38.6)	.249
Yes	21 (51.2)	20 (48.8)	
History skin tears 6-months			
No	65 (59.6)	44 (40.4)	.814
Yes	37 (57.8)	27 (42.2)	
History skin tears 12-months			
No	50 (59.5)	34 (40.5)	.883
Yes	52 (58.4)	37 (41.6)	
History of falls 1-months			
No	73 (57.5)	54 (42.5)	.511
Yes	29 (63.0)	17 (37.0)	
History of falls 3-months			
No	60 (60.0)	40 (40.0)	.745
Yes	42 (57.5)	31 (42.5)	

History of falls 6-months			
No	49 (67.1)	24 (32.9)	.062
Yes	53 (53.0)	47 (47.0)	
Falls risk category			
Medium	49 (59.0)	34 (41.0)	.984
High	53 (58.9)	37 (41.1)	
Fitzpatrick skin type			
Type 1	3 (33.3)	6 (66.7)	.302
Type 2	34 (65.4)	18 (34.6)	
Type 3	44 (56.4)	34 (43.6)	
Type 4	21 (61.8)	13 (38.2)	
Upper limb oedema			
No	101 (59.1)	70 (40.9)	.796
Yes	1 (50.0)	1 (50.0)	
Lower limb oedema			
No	59 (61.5)	37 (38.5)	.456
Yes	43 (55.8)	34 (44.2)	
ADL personal hygiene			
Supervision	4 (50.0)	4 (50.0)	.598
Physical assistance	98 (59.4)	67 (40.6)	
Nutrition			
Well nourished	73 (56.6)	56 (43.4)	.083
Resident obese	19 (57.6)	14 (42.4)	
Underweight and frail	10 (90.9)	1 (9.1)	
Assistance with nutrition			
Independent	9 (64.3)	5 (35.7)	.906
Requires supervision	71 (58.2)	51 (41.8)	
Needs physical assist	22 (59.5)	15 (40.5)	
ADL toileting			
Independent	4 (57.1)	3 (42.9)	.983
Supervision	27 (60.0)	18 (40.0)	
Physical assistance	71 (58.7)	50 (41.3)	
Wandering			
No issue	64 (58.2)	46 (41.8)	.958
Occasionally	8 (61.5)	5 (38.5)	
Regularly	30 (60.0)	20 (40.0)	
Agitation			
None or occasional	40 (55.6)	32 (44.4)	.442
Moderate to severe	62 (61.4)	39 (38.6)	
Cornell scale for depression			
0-8	30 (57.7)	22 (42.3)	.896
9-13	31 (56.4)	24 (43.6)	
14-18	26 (60.5)	17 (39.5)	
19-38	15 (65.2)	8 (34.8)	
Depression			
No	18 (60.0)	12 (40.0)	.899
Yes	84 (58.7)	59 (41.3)	
Behavioural needs scale			
Low	20 (58.8)	14 (41.2)	.743
Medium	21 (53.8)	18 (46.2)	
High	61 (61.0)	39 (39.0)	

Sleep patterns			
Normal sleep patterns	25 (59.5)	17 (40.5)	.136
Sleep occasionally disturbed	54 (54.0)	46 (46.0)	
Severe sleep disturbance	23 (74.2)	8 (25.8)	
Allergies present			
No	56 (56.0)	44 (44.0)	.354
Yes	46 (63.0)	27 (37.0)	
Heart disease			
No	63 (63.0)	37 (37.0)	.206
Yes	39 (53.4)	34 (46.6)	
Atrial fibrillation			
No	88 (59.9)	59 (40.1)	.565
Yes	14 (53.8)	12 (46.2)	
Angina			
No	95 (59.0)	6 (41.0)	.964
Yes	7 (58.3)	5 (41.7)	
Myocardial infarction			
No	97 (61.4)	61 (38.6)	.035*
Yes	5 (33.3)	10 (66.7)	
Ischaemic heart disease			
No	90 (58.4)	64 (41.6)	.693
Yes	12 (63.2)	7 (36.8)	
Congested cardiac failure			
No	96 (60.0)	64 (40.0)	.329
Yes	6 (46.2)	7 (53.8)	
Respiratory disease			
No	88 (57.9)	64 (42.1)	.444
Yes	14 (66.7)	7 (33.3)	
COPD			
No	87 (58.0)	63 (42.0)	.512
Yes	15 (62.5)	8 (34.8)	
Asthma			
No	96 (58.9)	67 (41.1)	.945
Yes	6 (60.0)	4 (40.0)	
Hypothyroidism			
No	86 (59.7)	58 (40.3)	.650
Yes	16 (55.2)	13 (44.8)	
Diabetes			
No	68 (54.8)	56 (45.2)	.116
Type 1	3 (100)	0 (0.0)	
Type 2	31 (67.4)	15 (32.6)	
Renal disease			
No	92 (59.4)	63 (40.6)	.756
Yes	10 (55.6)	8 (44.4)	
Paralysis			
No	97 (58.4)	69 (41.6)	.494
Yes	5 (71.4)	2 (28.6)	
CVA			
No	82 (58.2)	59 (41.8)	.652
Yes	20 (62.5)	12 (37.5)	
Hypertension			
No	36 (52.2)	33 (47.8)	.139
Yes	66 (63.5)	38 (36.5)	

Cancer			
No	90 (62.5)	54 (37.5)	.035*
Yes	12 (41.1)	17 (58.6)	
Osteoarthritis			
No	56 (59.6)	38 (40.4)	.858
Yes	46 (58.2)	33 (41.8)	
Rheumatoid arthritis			
No	98 (58.7)	69 (41.3)	.696
Yes	4 (66.7)	2 (33.3)	
Osteoporosis			
No	42 (50.6)	41 (49.4)	.032*
Yes	60 (66.7)	30 (33.3)	
Parkinson disease			
No	93 (58.5)	66 (41.5)	.673
Yes	9 (64.3)	5 (35.7)	
Dementia			
No	28 (36.4)	49 (63.6)	.263
Yes	43 (44.8)	53 (55.2)	
Anxiety			
No	62 (48.1)	67 (51.9)	.001**
Yes	9 (20.5)	35 (79.5)	
Skin moisture			
Rarely moist	43 (46.7)	49 (53.3)	.236
Occasionally moist	17 (37.0)	29 (63.0)	
Constantly moist	11 (31.4)	24 (68.6)	
Braden scale friction score			
No apparent problem	20 (74.1)	7 (25.9)	.215
Potential problem	42 (55.3)	34 (44.7)	
Problem	40 (57.1)	30 (42.9)	
Anti-inflammatories			
No	93 (59.6)	63 (40.4)	.595
Yes	9 (52.9)	8 (47.1)	
Diuretics			
No	44 (40.7)	64 (59.3)	.918
Yes	27 (41.5)	38 (58.5)	
Antipsychotics			
No	81 (59.1)	56 (40.9)	.932
Yes	21 (58.3)	15 (41.7)	
Antidepressants			
No	48 (55.2)	39 (44.8)	.308
Yes	54 (62.8)	32 (37.2)	
Antihypertensives			
No	49 (59.8)	33 (40.2)	.840
Yes	53 (58.2)	38 (41.8)	
Corticosteroid medications			
No	69 (58.0)	50 (42.0)	.698
Yes	33 (61.1)	21 (38.9)	
Oral corticosteroids			
No	97 (59.5)	66 (40.5)	.553
Yes	5 (50.0)	5 (50.0)	
Topical corticosteroids			
No	79 (58.5)	56 (41.5)	.824
Yes	23 (60.5)	15 (39.5)	

Inhalation corticosteroids			
No	93 (58.1)	67 (41.9)	.434
Yes	9 (69.2)	4 (30.8)	
Anticoagulants			
No	97 (59.1)	67 (40.9)	.831
Yes	5 (55.6)	4 (44.4)	
Antiplatelets			
No	64 (62.1)	39 (37.9)	.303
Yes	38 (54.3)	32 (45.7)	
Opioids			
No	75 (57.3)	56 (42.7)	.420
Yes	27 (64.3)	15 (35.7)	
Sedative			
No	86 (59.7)	58 (40.3)	.650
Yes	16 (55.2)	13 (44.8)	
Skin characteristics			
Vascular skin lesion			
Nil	39 (60.0)	26 (40.0)	.556
Purpura	40 (62.5)	24 (37.5)	
Purpura and ecchymosis	23 (52.3)	21 (47.7)	
Purpura all sites ≤ 20 mm			
No	39 (60.0)	26 (40.0)	.829
Yes	63 (58.3)	45 (41.7)	
Purpura ≤ 20 mm arms			
No	50 (61.0)	32 (39.0)	.609
Yes	52 (57.1)	39 (42.9)	
Purpura ≥ 20 mm legs			
No	64 (59.3)	44 (40.7)	.918
Yes	38 (58.5)	27 (41.5)	
Ecchymosis all sites ≥ 20 mm			
No	79 (61.2)	50 (38.8)	.296
Yes	23 (52.3)	21 (47.7)	
Ecchymosis ≥ 20 mm arms			
No	90 (60.8)	58 (39.2)	.228
Yes	12 (48.0)	13 (52.0)	
Ecchymosis ≥ 20 mm legs			
No	87 (60.4)	57 (39.6)	.385
Yes	15 (51.7)	14 (48.3)	
Bruising			
No	98 (58.3)	70 (41.7)	.332
Yes	4 (80.0)	1 (20.0)	
Haematoma			
No	102 (59.0)	71 (41.0)	—
Yes	0 (0.0)	0 (0.0)	
Presence scar tissue			
No	41 (73.2)	15 (26.8)	.008**
Yes	61 (52.1)	56 (47.9)	
Pseudoscars			
No	94 (58.4)	67 (41.6)	.574
Yes	8 (66.7)	4 (33.3)	

Dermatological skin condition			
No	96 (58.5)	68 (41.5)	.629
Yes	6 (66.7)	3 (33.3)	
Density hair arms			
Light	83 (63.4)	48 (36.6)	.063
Moderate	14 (41.2)	20 (58.8)	
Heavy	5 (62.5)	3 (37.5)	
Density hair legs			
Light	90 (58.4)	64 (41.6)	.693
Moderate	12 (63.2)	7 (36.8)	
Lax appearance			
Minimal	37 (52.9)	33 (47.1)	.179
More severe	65 (63.1)	38 (36.9)	
Fine wrinkles			
Mild	33 (36.3)	58 (63.7)	<.001**
Moderate/severe	69 (84.1)	13 (15.9)	
Coarse wrinkles			
None - mild	84 (75.7)	27 (24.3)	<.001**
Moderate - severe	18 (29.0)	44 (71.0)	
Lentigines			
None - mild	70 (66.0)	36 (34.0)	.017*
Moderate – severe	32 (47.8)	35 (52.2)	
Uneven pigmentation			
No	53 (85.5)	9 (14.5)	<.001**
Yes	49 (44.1)	62 (55.9)	
Yellowness			
None - mild	102 (59.3)	70 (39.6)	.229
Moderate - severe	0 (0.0)	1 (100)	
Permanent redness			
None - mild	95 (60.1)	63 (39.9)	.311
Moderate - severe	7 (46.7)	8 (53.3)	
History of actinic keratosis			
No	71 (77.2)	21 (22.8)	<.001**
Yes	31 (38.3)	50 (61.7)	
History of a malignant skin lesion			
No	81 (66.4)	41 (33.6)	.002**
Yes	21 (41.2)	30 (58.8)	
Cutis rhomboidalis nuchae			
No	84 (68.9)	38 (31.1)	<.001**
Yes	18 (35.3)	33 (64.7)	

Note. n = number (%). An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

An independent samples two-tailed *t*-test was performed to evaluate the difference in baseline continuous variables between participants with clinical manifestations of elastosis and participants without elastosis. The findings of this analysis are presented in Table 6.9.

Table 6.9. Independent *t*-test of Baseline Variables in Residents With and Without Clinical Manifestations of Elastosis

	No elastosis (n = 102)	Elastosis (n = 71)	
Variables	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>p</i> -value
General characteristics			
Precise age	86.34 (7.43)	88.93 (5.51)	.009**
Number of days in facility	10500.87 (1048.72)	779.94 (704.86)	.044*
Number of years living in Australia	73.14 (20.91)	81.82 (20.41)	.007**
Weight in kilograms	64.76 (15.49)	70.02 (16.39)	.033*
Height in centimetres	160.15 (8.74)	165.07 (8.26)	<.001**
Body mass index	25.22 (5.54)	26.04 (5.05)	.322
ADL precise score	80.60 (16.90)	79.04 (17.81)	.654
Number of chronic diseases	3.73 (1.48)	3.46 (1.56)	.266
Braden Scale score	17.67 (3.91)	18.86 (2.77)	.021*
Total number of medications	6.88 (3.19)	6.90 (3.71)	.971
Skin properties			
Mean melanin	29.64 (3.63)	30.21 (4.31)	.352
Mean TEWL upper extremities	7.15 (2.63)	8.88 (2.92)	<.001**
Mean TEWL lower extremities	5.01 (1.38)	5.63 (1.73)	.010**
Mean TEWL abdomen	5.11 (1.67)	5.05 (1.50)	.833
Mean hydration upper extremities	84.35 (31.23)	69.28 (30.18)	.002**
Mean hydration lower extremities	92.19 (34.90)	78.39 (34.39)	.011*
Mean hydration abdomen	137.75 (46.07)	126.74 (34.66)	.090
Mean pH upper extremities	5.69 (.51)	5.75 (.47)	.444
Mean pH lower extremities	5.78 (.46)	5.76 (.51)	.738
Mean pH abdomen	5.96 (.47)	5.93 (.44)	.639
Mean SLEB upper extremities	285.22 (79.69)	296.85 (89.33)	.370
Mean SLEB lower extremities	137.30 (73.85)	156.32 (66.00)	.084
Mean SLEB abdomen	65.92 (88.20)	56.48 (91.47)	.496
Mean skin thickness upper extremities	810.31 (265.13)	845.77 (179.04)	.205

Mean skin thickness lower extremities	1087.78 (265.13)	1102.62 (244.51)	.709
Mean skin thickness abdomen	1155.58 (259.73)	1223.29 (274.72)	.101
Mean skin intensity score upper extremities	45.70 (11.71)	42.49 (10.62)	.067
Mean skin intensity score lower extremities	47.17 (15.44)	44.92 (13.46)	.323
Mean skin intensity score abdomen	52.90 (22.11)	44.97 (20.81)	.019*
Mean VE upper extremities	4.31 (1.72)	4.05 (1.33)	.286
Mean VE lower extremities	2.55 (1.17)	2.30 (1.21)	.178
Mean VE abdomen	3.19 (2.01)	3.11 (2.02)	.796
Mean distensibility upper extremities	13.21 (2.73)	14.18 (2.31)	.015*
Mean distensibility lower extremities	16.59 (1.95)	16.50 (1.73)	.752
Mean distensibility abdomen	7.17 (2.82)	6.72 (2.65)	.289
Mean retraction upper extremities	4.55 (2.45)	6.38 (4.45)	.002**
Mean retraction lower extremities	3.64 (2.05)	4.40 (2.90)	.047*
Mean retraction abdomen	2.44 (3.14)	2.10 (1.95)	.417
Mean venous PPG right leg	11.49 (7.42)	14.66 (8.26)	.022*
Mean venous PPG left leg	11.33 (6.92)	12.80 (7.62)	.249
Mean TBPI right foot	.73 (.30)	.72 (.21)	.740
Mean TBPI left foot	.74 (.22)	.70 (.20)	.288

Transepidermal skin proteins

Mean type IV collagen pixels' forearm	79630.18 (22645.99)	76073.28 (23970.06)	.323
Mean type IV collagen mean intensity forearm	21.72 (15.56)	27.38 (20.06)	.048*
Mean type IV collagen SD intensity forearm	9.59 (6.56)	11.65 (8.42)	.073
Mean type IV collagen pixels' leg	79012.84 (24594.27)	78644.86 (24747.26)	.923
Mean type IV collagen mean intensity leg	21.52 (14.92)	26.60 (23.99)	.088
Mean type IV collagen SD intensity leg	9.54 (5.65)	11.64 (11.87)	.169

Mean MMP2 pixels' forearm	78946.83 (22943.84)	79105.62 (25987.71)	.966
Mean MMP-2 mean intensity forearm	21.27 (30.59)	20.11 (20.17)	.781
Mean MMP-2 <i>SD</i> intensity forearm	11.97 (11.15)	12.18 (11.37)	.900
Mean MMP-2 pixels' leg	80165.13 (23519.15)	79746.34 (25132.76)	.911
Mean MMP-2 mean intensity leg	18.12 (23.96)	17.03 (19.95)	.752
Mean MMP-2 <i>SD</i> intensity leg	11.49 (10.17)	11.05 (13.42)	.808
Mean TNF-alpha forearm	79150.75 (23160.73)	81440.06 (26549.52)	.548
Mean TNF-alpha mean intensity forearm	70.05 (78.81)	59.59 (72.67)	.377
Mean TNF-alpha <i>SD</i> intensity forearm	15.88 (11.57)	17.01 (13.78)	.573
Mean TNF-alpha pixels' leg	80919.35 (25007.65)	80741.23 (25221.83)	.963
Mean TNF-alpha mean intensity leg	72.43 (81.66)	58.79 (72.97)	.261
Mean TNF-alpha <i>SD</i> intensity leg	15.72 (9.91)	16.30 (12.10)	.730

Note. *M* = mean; *SD* = standard deviation; *p*-value = 2-tailed significance; TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band. An asterisk (*) indicates a statistically significant difference, * = *p* < 0.05; ** = *p* < 0.01.

A significant difference was identified between participants with clinical elastosis and participants without clinical elastosis for the following variables: age; number of days residing in the facility; number of years living in Australia; weight; height; Braden Scale Score; TEWL upper extremities; TEWL lower extremity; hydration upper extremities; hydration lower extremities; skin intensity score abdomen; distensibility upper extremities; skin retraction upper extremities; skin retraction lower extremities; and type IV collagen intensity forearm. The difference in the Braden Scale Score, which is measured to evaluate the risk of developing a pressure ulcer, did not make any biological or clinical sense between participants with and without cutaneous manifestations of elastosis.

Univariable and multivariable logistic regression was performed to estimate the odds ratio for each baseline variables and the risk of baseline cutaneous manifestations of elastosis. The dependent variable (clinical elastosis) was categorised as 0 = no clinical elastosis and 1 = clinical elastosis. The findings from the analyses are reported in Table 6.10.

Table 6.10. Results of Univariable and Multivariable Analysis of Baseline Variables Associated with Elastosis at Baseline

Variables	Elastosis at baseline (Univariable)	Elastosis at baseline (Multivariable)
	Odds ratio (95% CI)	Odds ratio (95% CI)
Individual characteristics		
Age	1.06 (1.01-1.11) (p = .016)	1.12 (1.03–1.22) (p = .006)
Sex (males vs. females)	4.34 (2.16-8.74) (p < .0005)	3.65 (1.27–10.52) (p = .016)
History of smoking (ex-smoker vs. life-long non-smoker)	2.68 (1.40-5.13) (p = .003)	2.61 (1.06–6.44) (p = .037)
Skin characteristics		
Uneven pigmentation (yes vs. no)	7.45 (3.35-16.58) (p < .001)	8.09 (2.71–24.16) (p < .001)
History of actinic keratosis (yes vs. no)	5.45 (2.81-10.57) (p < .001)	2.95 (1.24–7.01) (p = .014)
Cutis rhomboidalis nuchae (yes vs. no)	4.05 (2.03-8.08) (p < .000)	3.56 (1.32–9.64) (p = .012)
Skin properties		
Mean elasticity upper extremities	1.17 (1.03-1.32) (p = .016)	
Collagen IV mean intensity upper extremities	1.02 (1.00-1.04) (p = .042)	1.05 (1.01–1.08) (p = .004)

Note. OR = odds ratio; CI = confidence interval; p = p-value; vs = versus.

Univariable analysis identified eight variables that were potential predictors of clinical elastosis. Subsequent multivariable analysis identified seven variables that were significantly associated with clinical elastosis.

These variables comprised of three individual characteristics (age, gender, history of smoking); three skin characteristics (uneven pigmentation; history of AK; cutis rhomboidalis); and a single skin property that were significantly associated with cutaneous manifestations of elastosis (collagen IV mean intensity upper extremities).

After adjusting for age, gender, history of skin tears, history of falls and BMI the multivariable analysis was conducted to evaluate all variables to determine the risk of clinical manifestations of elastosis. The results of this analysis are presented in Table 6.11.

Table 6.11. Multivariable Analysis (95% CI) of Baseline Variables in Residents (n=173) with Clinical Elastosis

Variables	Cutaneous manifestations of elastosis	
	OR (95% CI)	<i>p-value</i>
Precise age (years and months)	1.12 (1.03–1.22)	.006
Gender		
Females	1	
Males	3.65 (1.27–10.52)	.016
Uneven skin pigmentation		
No	1	
Yes	8.09 (2.71–24.16)	< .001
Cutis rhomboidalis nuchae		
No	1	
Yes	3.56 (1.32–9.64)	.012
History of smoking		
Life-long non-smoker	1	
Ex-smoker	2.61 (1.06–6.44)	.037
History of AK		
No	1	
Yes	2.95 (1.24–7.01)	.014
Collagen type IV mean intensity forearm	1.05 (1.01–1.08)	.004

Note. CI = confidence interval; AK = actinic keratosis.

Multivariable analysis identified three individual variables (age, gender, smoking), three clinical skin variables (uneven skin pigmentation, cutis rhomboidalis nuchae, history of AK) and one skin property variable (collagen type IV mean intensity of the dorsal forearm) to be statistically significantly

associated with cutaneous manifestations of elastosis. As collagen type IV was only significant at the dorsal forearm, a Pearson's Product-Moment Correlation Coefficient was performed to better understand the relationship between all upper extremity baseline skin properties and participants with clinical manifestations of elastosis. The results of this analysis are presented in Table 6.12.

Table 6.12. Pearson's Coefficient for Clinical Elastosis and Skin Properties of Dorsal Forearms

Elastosis	Mean TEWL	Mean hydration	Mean pH	Mean SLEB	Mean thickness	Mean intensity	Mean VE	Mean distensibility	Mean retraction	Mean Type IV collagen	MMP-2 mean intensity
Mean hydration	-.332**										
Mean pH	.190	-.252*									
Mean SLEB	-.109	.164	-.077								
Mean thickness	.071	-.157	.029	.529**							
Mean skin intensity score	-.281*	.340**	-.095	-.166	-.229						
Mean VE	-.122	.409**	-.160	.034	-.105	.342**					
Mean distensibility	.250*	-.270*	.044	-.063	.311**	-.067	-.074				
Mean retraction	.118	-.324**	.230	-.114	-.043	-.316**	-.592**	.230			
Mean type IV collagen	-.223	.291*	-.337**	.100	.006	.100	.348**	-.009	-.227		
MMP-2 mean intensity	-.074	-.045	-.403**	.033	-.091	-.047	.040	-.123	-.177	.450**	
TNF- α mean intensity	.212	-.102	.164	.124	.045	-.060	-.227	.151	.169	-.326**	-.217

Note. An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

A moderately negative association ($p < .01$) was identified between hydration and TEWL, retraction and hydration, retraction and skin structural intensity, MMP-2 and pH, and TNF- α and collagen type IV in participants with elastotic skin manifestations ($n = 71$). A large negative association ($p < .01$) was found between retraction and VE. A moderately positive association ($p < .01$) was identified between skin structural intensity and hydration, VE and hydration, VE and intensity, distensibility and skin thickness, retraction and skin structural intensity, collagen type IV and VE, and between MMP-2 and collagen type IV with elastosis skin changes. A large positive association ($p < .01$) was identified between skin thickness and SLEB.

6.3.8. Skin purpura.

Age related purpura are non-inflammatory ecchymotic skin lesions that ranged in diameter between 2–20mm. Purpura was a significant and independent risk factor for skin tears (Table 6.7). Chi-square tests were conducted to test if there were any significant differences between baseline individual and skin characteristics and participants with and without purpura. The results of those analyses are presented in Table 6.13.

Table 6.13. Chi-square of Baseline Variables Associated with Purpura

Variables	No purpura n (%)	Purpura n (%)	p-value
Individual characteristics			
Gender			
Males	18 (36.0)	32 (64.0)	.789
Females	47 (38.2)	76 (61.8)	
Past history of smoking			
No	34 (35.1)	63 (64.9)	.536
Yes	27 (40.9)	39 (59.1)	
Place of birth			
Oceanian	41 (34.5)	78 (65.5)	.283
North-West European	20 (52.6)	18 (47.4)	
Southern and Eastern European	3 (42.9)	4 (57.1)	
South-East Asian	0 (0.0)	2 (100)	
North-East Asian	0 (0.0)	1 (100)	
Southern and Central Asian	0 (0.0)	1 (100)	
People of the Central Americans	(0.0)	3 (100)	
Sub-Saharan African	1 (50.0)	1 (50.0)	
Previous occupation			
Managers and administrators	1 (14.3)	6 (85.7)	.409
Professionals	13 (37.1)	22 (62.9)	
Associate professionals	4 (40.0)	6 (60.0)	
Trades and related workers	3 (23.1)	10 (76.9)	
Advanced clerical and service	1 (16.7)	5 (83.3)	
Inter clerical, sales and service	3 (21.4)	11 (78.6)	
Production and transport workers	4 (57.1)	3 (42.9)	
Elementary sales and service	28 (44.4)	35 (55.6)	
Labourers	8 (44.4)	10 (55.6)	
Principle work environment			
Mix indoor/outdoor work	7 (30.4)	16 (69.6)	.448
Primarily worked outdoors	58 (38.7)	92 (61.3)	
Mobility impairment			
No	23 (56.1)	18 (43.9)	.005**
Yes	42 (31.8)	90 (68.2)	
Activity level			
Walks frequently	37 (48.7)	39 (51.3)	.019
Walks occasionally	17 (26.6)	47 (73.4)	
Bedfast and chairfast	11 (33.3)	22 (66.7)	
Mobility			
Independent	14 (60.9)	9 (39.1)	.076
Supervision	25 (40.3)	37 (59.7)	
Physical assistance	26 (29.5)	62 (70.5)	
Mobility assistance			
No limitation	14 (58.3)	10 (41.7)	.056
Assist	40 (33.9)	78 (66.1)	
Bedfast or chairfast	11 (35.5)	20 (64.5)	

Ability to transfer			
Independent	38 (45.8)	45 (54.2)	.188
Assist	15 (25.9)	43 (74.1)	
Mechanical lifting device	12 (37.5)	20 (62.5)	
Ability to reposition self			
No	30 (33.0)	61 (67.0)	.511
Yes	35 (42.7)	47 (57.3)	
Visual impairment			
Normal vision	10 (55.6)	8 (44.4)	.211
Blurred/cataracts/glaucoma	52 (36.1)	92 (63.9)	
Severe impairment	3 (27.3)	8 (72.7)	
Uses a visual aid			
No	12 (52.2)	11 (47.8)	.120
Yes	53 (35.5)	97 (64.7)	
Sensory impairment			
No	22 (48.9)	23 (51.1)	.068
Yes	43 (33.6)	85 (66.4)	
Incontinence/continence			
Continent	5 (33.3)	10 (66.7)	.236
Urinary	24 (43.6)	31 (56.4)	
Faecal	4 (80.0)	1 (20.0)	
Urinary and faecal	32 (32.7)	66 (67.3)	
Type of skin cleanser used			
Soap	44 (40.0)	66 (60.0)	.222
pH neutral cleanser	18 (30.5)	41 (69.5)	
Moisturiser used			
No	22 (38.6)	35 (61.4)	.845
Yes	43 (37.1)	73 (62.9)	
PAS scale			
No impairment	23 (44.2)	29 (55.8)	.137
Mild impairment	23 (41.8)	32 (58.2)	
Moderate impairment	15 (34.9)	28 (65.1)	
Severe impairment	4 (17.9)	19 (82.6)	
PAS scale			
None or mild impairment	21 (32.3)	44 (67.7)	.267
Moderate-severe impairment	44 (40.7)	64 (59.3)	
ADL scale			
Low	6 (37.5)	10 (62.5)	.360
Medium	31 (43.7)	40 (56.3)	
High	28 (32.6)	58 (67.4)	
History skin tears 3-months			
No	57 (43.2)	75 (56.8)	.006**
Yes	8 (19.5)	33 (80.5)	
History skin tears 6-months			
No	57 (52.3)	52 (47.7)	<.001*
Yes	8 (12.5)	56 (87.5)	
History skin tears 12-months			
No	52 (61.9)	32 (38.1)	<.001*
Yes	13 (14.6)	76 (85.4)	

History of falls 1-months			
No	55 (43.3)	72 (56.7)	.010**
Yes	10 (21.7)	36 (78.3)	
History of falls 3-months			
No	48 (48.0)	52 (52.0)	.001**
Yes	17 (23.3)	56 (76.7)	
History of falls 6-months			
No	36 (49.3)	37 (50.7)	.006**
Yes	29 (29.0)	71 (71.0)	
Falls risk category			
Medium	46 (55.4)	37 (44.6)	<.001**
High	19 (21.1)	71 (78.9)	
Venous PPG right leg			
> 20 seconds	10 (43.5)	13 (56.5)	.783
< 20 seconds	44 (40.4)	65 (59.6)	
Venous PPG left leg			
> 20 seconds	12 (57.1)	9 (42.9)	.099
< 20 seconds	42 (37.8)	69 (62.2)	
Fitzpatrick skin type			
Type 1	44.4 (4)	5 (55.6)	.175
Type 2	26.9 (14)	38 (73.1)	
Type 3	38.5 (30)	48 (61.5)	
Type 4	50.0 (17)	17 (50.0)	
Upper extremity oedema			
No	64 (37.4)	107 (62.6)	.715
Yes	1 (50.0)	1 (50.0)	
Lower extremity oedema			
No	35 (36.5)	61 (63.5)	.736
Yes	30 (39.0)	47 (61.0)	
ADL personal hygiene			
Supervision	5 (62.5)	3 (37.5)	.036*
Physical assistance	60 (36.4)	100 (63.6)	
Nutrition			
Well nourished	50 (38.8)	79 (61.2)	.389
Resident obese	13 (39.4)	20 (60.6)	
Underweight and frail	2 (18.2)	9 (81.8)	
Assistance with nutrition			
Independent	5 (35.7)	9 (64.3)	.989
Requires supervision	46 (37.7)	76 (62.3)	
Needs physical assistance	14 (37.8)	23 (62.2)	
ADL toileting			
Independent	4 (57.1)	3 (42.9)	.372
Supervision	19 (42.2)	26 (57.8)	
Physical assistance	42 (34.7)	79 (65.3)	
Wandering			
No issue	35 (31.8)	75 (68.2)	.118
Occasionally	6 (46.2)	7 (53.8)	
Regularly	24 (48.0)	26 (52.0)	
Agitation			
None/occasional issue	29 (40.3)	43 (59.7)	.535
Moderate/severe issue	36 (35.6)	65 (64.4)	

Cornell scale for depression			
0-8	23 (44.2)	29 (55.8)	.137
9-13	23 (41.8)	32 (58.2)	
14-18	15 (34.9)	28 (65.1)	
19-38	4 (17.4)	19 (82.6)	
Depression			
No	10 (33.3)	20 (66.7)	.598
Yes	55 (38.5)	88 (61.5)	
Behavioural needs scale			
Low	14 (41.2)	20 (58.8)	.387
Medium	11 (28.2)	28 (71.8)	
High	40 (40.0)	60 (60.0)	
Sleep patterns			
Normal sleep patterns	18 (42.9)	24 (57.1)	.671
Sleep disturbance at times	35 (35.0)	65 (65.0)	
Severe sleep disturbance	12 (38.7)	19 (61.3)	
Allergies			
No	35 (35.0)	65 (65.0)	.414
Yes	30 (41.1)	43 (58.9)	
Heart disease			
No	42 (42.0)	58 (58.0)	.159
Yes	23 (31.5)	50 (68.5)	
AF			
No	59 (40.1)	88 (59.9)	.098
Yes	6 (23.1)	20 (76.9)	
Angina			
No	60 (37.3)	101 (62.7)	.761
Yes	5 (41.7)	7 (58.3)	
MI			
No	60 (38.0)	98 (62.0)	.723
Yes	5 (33.3)	10 (66.7)	
IHD			
No	58 (37.7)	96 (62.3)	.944
Yes	7 (36.8)	12 (63.2)	
CCF			
No	64 (40.0)	96 (60.0)	.021*
Yes	1 (7.7)	12 (92.3)	
Respiratory disease			
No	61 (40.1)	91 (59.9)	.061
Yes	4 (19.0)	17 (81.0)	
COPD			
No	62 (41.3)	88 (58.7)	.009**
Yes	3 (13.0)	20 (87.0)	
Asthma			
No	63 (38.7)	100 (61.3)	.237
Yes	2 (20.0)	8 (80.0)	
Hypothyroidism			
No	55 (38.2)	89 (61.8)	.707
Yes	10 (34.5)	19 (65.5)	

Diabetes type				
No	41 (33.1)	83 (66.9)	.121	
Type 1	2 (66.7)	1 (33.3)		
Type 2	22 (47.8)	24 (52.2)		
Renal disease				
No	60 (38.7)	95 (61.3)	.365	
Yes	5 (27.8)	13 (72.2)		
Paralysis				
No	61 (36.7)	105 (63.3)	.275	
Yes	4 (57.1)	3 (42.9)		
Contractures				
No	63 (37.7)	104 (62.3)	.827	
Yes	2 (33.3)	4 (66.7)		
CVA				
No	56 (39.7)	85 (60.3)	.222	
Yes	9 (28.1)	23 (71.9)		
Hypertension				
No	26 (37.7)	43 (62.3)	.981	
Yes	39 (37.5)	65 (62.5)		
Cancer				
No	55 (38.2)	89 (61.8)	.707	
Yes	10 (34.5)	19 (65.5)		
Osteoarthritis				
No	47 (50.0)	47 (50.0)	<.001**	
Yes	18 (22.8)	61 (77.2)		
Rheumatoid arthritis				
No	62 (37.1)	105 (62.9)	.522	
Yes	3 (50.0)	3 (50.0)		
Osteoporosis				
No	35 (42.2)	48 (57.8)	.231	
Yes	30 (33.3)	60 (66.7)		
Parkinson disease				
No	61(38.4)	98 (61.6)	.468	
Yes	4 (28.6)	10 (71.4)		
Anxiety				
No	48 (37.2)	81 (62.8)	.866	
Yes	17 (38.6)	27 (61.4)		
Dementia				
No	23 (29.9)	54 (70.1)	.061	
Yes	42 (43.8)	54 (56.3)		
Skin moisture				
Rarely moist	36 (39.1)	56 (60.9)	.882	
Occasionally moist	16 (34.8)	30 (65.2)		
Constantly moist	13 (37.1)	22 (62.9)		
Braden Scale friction score				
No apparent problem	34 (48.6)	36 (51.4)	.044*	
Potential problem	22 (28.9)	54 (71.1)		
Problem	9 (33.3)	18 (66.7)		
Anti-inflammatories				
No	59 (37.8)	97 (62.2)	.838	
Yes	6 (35.3)	11 (64.7)		

Diuretics				
No	46 (42.6)	62 (57.4)	.079	
Yes	19 (29.2)	46 (70.8)		
Antipsychotic				
No	51 (37.2)	86 (62.8)	.855	
Yes	14 (38.9)	22 (61.1)		
Antidepressants				
No	35 (40.2)	52 (59.8)	.468	
Yes	30 (34.9)	56 (65.1)		
Antihypertensives				
No	34 (41.5)	48 (58.5)	.316	
Yes	31 (34.1)	60 (65.9)		
Corticosteroid medication				
No	47 (39.5)	72 (60.5)	.438	
Yes	18 (33.3)	36 (66.7)		
Oral corticosteroid medication				
No	61 (37.4)	102 (62.6)	.870	
Yes	4 (40.0)	6 (60.0)		
Topical corticosteroid medication				
No	53 (39.3)	82 (60.7)	.388	
Yes	12 (31.6)	26 (68.4)		
Inhalation corticosteroid medication				
No	62 (38.8)	98 (61.3)	.262	
Yes	3 (23.1)	10 (76.9)		
Anticoagulants				
No	61 (37.2)	103 (62.8)	.662	
Yes	4 (44.4)	5 (55.6)		
Antiplatelets				
No	44 (42.7)	59 (57.3)	.090	
Yes	21 (30.0)	49 (70.0)		
Opioids				
No	53 (40.5)	78 (59.5)	.166	
Yes	12 (28.6)	30 (71.4)		
Sedatives				
No	55 (38.2)	89 (61.8)	.707	
Yes	10 (34.5)	19 (65.5)		
Skin characteristics				
Bruising				
No	61 (36.3)	107 (63.7)	.047*	
Yes	4 (80.0)	1 (20.0)		
Haematoma				
No	65 (37.6)	10 (62.4)	—	
Yes	0 (0.0)	0 (0.0)		
Scars				
No	26 (46.4)	30 (53.6)	.096	
Yes	39 (33.3)	78 (66.7)		
Pseudoscars				
No	64 (39.8)	97 (60.2)	.030*	
Yes	1 (8.3)	11 (91.7)		

Hair upper extremities			
Light	49 (37.4)	82 (62.6)	.996
Moderate	13 (38.2)	21 (61.8)	
Heavy	3 (37.5)	5 (62.5)	
Hair lower extremities			
Light	53 (34.4)	101 (65.6)	.015*
Moderate	12 (63.2)	7 (36.8)	
Lax appearance			
None - mild	37 (52.9)	33 (47.1)	.001**
Moderate - severe	28 (27.2)	75 (72.8)	
Fine wrinkles			
None - mild	29 (31.9)	62 (68.1)	.103
Moderate - severe	36 (43.9)	46 (56.1)	
Coarse wrinkles			
None - mild	45 (40.5)	66 (59.5)	.281
Moderate - severe	20 (32.3)	42 (67.7)	
Lentigines			
None - mild	42 (39.6)	64 (60.4)	.484
Moderate – severe	23 (34.3)	44 (65.7)	
Uneven pigmentation			
No	27 (43.5)	35 (56.5)	.225
Yes	38 (34.2)	73 (65.8)	
Yellowness			
None - mild	65 (37.8)	107 (62.2)	.437
Moderate - severe	0 (0.0)	1 (100)	
Elastosis			
None - mild	39 (40.3)	86 (59.7)	.102
Moderate - severe	26 (24.1)	22 (75.9)	
Cutis rhomboidalis nuchae			
No	52 (42.6)	70 (57.4)	.034*
Yes	13 (25.5)	38 (74.5)	
Permanent erythema			
None - mild	57 (36.1)	101 (63.9)	.187
Moderate - severe	8 (53.3)	7 (46.7)	
Actinic keratosis			
No	40 (43.5)	52 (56.5)	.087
Yes	25 (30.9)	56 (69.1)	
Malignant skin lesion			
No	51 (41.8)	71 (58.2)	.076
Yes	14 (27.5)	37 (72.7)	

Note. n = number (%). An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

Purpura was present in two-thirds of all participants, with 61.8% of males and 64% of female participants exhibiting clinical manifestations. Individual characteristics that were significantly associated with purpura included: mobility impairment; activity level; history of skin tears in the previous 3-months, 6-months and 12-months; history of falls in the previous 1-month, 3-

months and 6-months; falls risk category; personal hygiene; CCF; COPD; osteoarthritis; and Braden Scale Score for friction. Clinical factors significantly associated with purpura included: bruising; pseudoscars; presence light hair across the extremities; lax appearance of skin; and cutis rhomboidalis nuchae.

An independent samples two-tailed *t*-test evaluated the difference in mean baseline continuous variables between participants with clinical purpura and participants without purpura. The results of the *t*-test analyses are presented in Table 6.14.

Table 6.14. Independent t-test of Baseline Variables in Residents With and Without Clinical Manifestations of Purpura

	No purpura (n = 65)	Purpura (n = 108)	
Variables	<i>M</i> (<i>SD</i>)	<i>M</i> (<i>SD</i>)	<i>p</i> -value
Individual characteristics			
Precise age	85.19 (7.68)	88.74 (5.87)	.002**
Number of days in facility	972.38 (988.01)	920.00 (898.31)	.721
Number of years living in Australia	72.11 (22.32)	79.46 (19.90)	.026*
Weight in kilograms	67.56 (15.71)	66.54 (16.28)	.686
Height in centimetres	162.62 (7.86)	161.90 (9.44)	.608
Body mass index	25.94 (4.90)	25.33 (5.60)	.472
ADL precise score	79.02 (17.29)	80.76 (17.25)	.522
Number of chronic diseases	3.20 (1.48)	3.87 (1.48)	.004**
Braden Scale score	18.86 (3.67)	17.73 (3.42)	.042*
Total number of medications	6.77 (4.05)	6.96 (2.98)	.738
Skin properties			
Mean melanin	30.36 (4.08)	29.58 (3.81)	.202
Mean TEWL upper extremities	7.33 (2.79)	8.18 (2.89)	.061
Mean TEWL lower extremities	5.05 (1.48)	5.39 (1.60)	.173
Mean TEWL abdomen	4.82 (1.48)	5.24 (1.65)	.095
Mean hydration upper extremities	80.05 (32.88)	77.03 (30.90)	.543
Mean hydration lower extremities	87.04 (33.70)	86.21 (36.31)	.881
Mean hydration abdomen	145.31 (50.75)	125.96 (33.97)	.003**
Mean pH upper extremities	5.51 (.46)	5.84 (.47)	<.001**
Mean pH lower extremities	5.57 (.44)	5.89 (.46)	<.001**
Mean pH abdomen	5.72 (.44)	6.08 (.41)	<.001**
Mean SLEB upper extremities	290.81 (71.66)	289.50 (90.53)	.921
Mean SLEB lower extremities	132.73 (77.64)	152.56 (66.21)	.076
Mean SLEB abdomen	65.78 (109.67)	59.80 (75.12)	.671
Mean skin thickness upper extremities	894.38 (181.99)	783.02 (167.09)	<.001**
Mean skin thickness lower extremities	1149.04 (270.75)	1060.67 (242.37)	.028*

Mean skin thickness abdomen	1190.78 (285.73)	1178.90 (256.82)	.778
Mean skin intensity score upper extremities	44.98 (12.05)	44.02 (10.96)	.590
Mean skin intensity score lower extremities	45.54 (15.02)	46.68 (14.50)	.621
Mean skin intensity score abdomen	44.29 (21.09)	52.87 (21.80)	.012*
Mean VE upper extremities	4.43 (1.76)	4.06 (1.44)	.135
Mean VE lower extremities	2.35 (1.12)	2.51 (1.23)	.391
Mean VE abdomen	3.32 (1.90)	3.05 (2.08)	.394
Mean distensibility upper extremities	14.32 (2.55)	13.18 (2.55)	.005**
Mean distensibility lower extremities	17.07 (1.50)	16.24 (1.99)	.002**
Mean distensibility abdomen	6.59 (2.50)	7.23 (2.83)	.137
Mean retraction upper extremities	4.77 (2.91)	5.62 (3.82)	.125
Mean retraction lower extremities	4.00 (2.80)	3.92 (2.24)	.832
Mean retraction abdomen	1.66 (1.63)	2.69 (3.13)	.005**
Mean venous PPG right leg	12.19 (7.50)	13.41 (8.24)	.385
Mean venous PPG left leg	13.09 (7.56)	11.24 (6.98)	.151
Mean TBPI right foot	.77 (.25)	.70 (.27)	.115
Mean TBPI left foot	.76 (.22)	.71 (.20)	.093

Transepidermal skin proteins

Mean type IV collagen pixels' forearm	77365.63 (24144.97)	78654.77 (22706.55)	.724
Mean type IV collagen mean intensity forearm	28.83 (19.73)	21.16 (15.79)	.009**
Mean type IV collagen SD intensity forearm	12.08 (8.43)	9.45 (6.60)	.024*
Mean type IV collagen pixels' leg	78245.51 (25797.89)	79232.75 (23942.04)	.799
Mean type IV collagen mean intensity leg	28.25 (18.10)	20.81 (19.49)	.013*
Mean type IV collagen SD intensity leg	13.10 (12.14)	8.77 (5.37)	.008**
Mean MMP2 pixels forearm	81009.62 (25252.18)	77809.73 (23525.33)	.401
Mean MMP-2 mean intensity forearm	26.93 (30.73)	17.10 (23.41)	.028*
Mean MMP-2 SD intensity forearm	15.13 (14.56)	10.20 (8.11)	.014*
Mean MMP-2 pixels leg	78385.72 (24062.95)	80960.75 (24219.54)	.498

Mean MMP-2 mean intensity leg	20.25 (22.65)	16.12 (22.12)	.240
Mean MMP-2 <i>SD</i> intensity leg	13.58 (15.10)	9.94 (8.61)	.079
Mean TNF-alpha forearm	82552.17 (25800.28)	78608.61 (23779.79)	.308
Mean TNF-alpha mean intensity forearm	54.53 (67.99)	72.51 (80.45)	.118
Mean TNF-alpha <i>SD</i> intensity forearm	14.91 (11.31)	17.21 (13.14)	.240
Mean TNF-alpha pixels' leg	79290.46 (24648.61)	81782.60 (25312.87)	.527
Mean TNF-alpha mean intensity leg	53.46 (69.38)	74.88 (82.44)	.069
Mean TNF-alpha <i>SD</i> intensity leg	15.34 (8.80)	16.33 (11.91)	.559

Note. *M* = mean; *SD* = standard deviation; TEWL = transepidermal water loss; SLEB = subepidermal low echogenicity band. An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

A significant difference was identified between participants with clinical purpura and participants without purpura for: age, years living in Australia, number of chronic diseases, Braden Scale friction score, pH across all test sites, skin thickness upper extremities and lower extremities, distensibility upper extremities and lower extremities, collagen type IV upper extremities and lower extremities, and MMP-2 forearms.

Univariable and multivariable logistic regression was performed to estimate the odds ratio for each baseline variables and the risk of baseline purpura. The dependent variable (purpura) was categorised as 0 = no purpura and 1 = purpura. The findings from the analyses are reported in Table 6.15.

Table 6.15. Results of Univariable and Multivariable Analysis of Baseline Variables Associated with Purpura at Baseline

Variables	Purpura at baseline (Univariable)	Purpura at baseline (Multivariable)
	Odds ratio (95% CI)	Odds ratio (95% CI)
Individual characteristics		
Age	1.08 (1.03-1.13) (p < .001)	1.08 (1.00–1.17) (p = .047)
History skin tears previous 12-months (yes vs. no)	9.50 (4.56-19.81) (p < .001)	14.57 (5.18–40.93) (p < .001)
Falls in previous 3- months (yes vs. no)	3.04 (1.56-5.94) (p < .001)	2.89 (1.10–7.61) (p = .031)
Antiplatelet therapy (yes vs. no)	1.74 (.92-3.31) (p = .091)	3.40 (1.26–9.17) (p = .016)
Skin characteristics		
Cutis rhomboidalis nuchae (yes vs. no)	2.17-1.05-4.48) (p = .036)	
Mean pH upper extremities	4.51 (2.18-9.33) (p < .001)	4.42 (1.60–12.19) (p = .004)
Mean SLEB upper extremities	1.00 (1.00-1.00) (p = .920)	1.01 (1.00–1.02) (p = .014)
Mean skin thickness upper extremities	1.00 (1.00-1.00) (p < .001)	.99 (.99–1.00) (p < .001)
Mean elasticity upper extremities	.83 (.73-.95) (p = .006)	
Collagen IV mean intensity upper extremities	.98 (.96-.99) (p = .008)	

Note. OR = odds ratio; CI = confidence interval; p = p-value; SLEB = subepidermal low echogenicity band; vs = versus.

Univariable analysis identified eight variables that were potential predictors of purpura. Subsequent multivariable analysis identified seven variables that were significantly associated with purpura. These variables comprised of four individual variables (age, history of skin tears in previous 12-months; history of falls in previous 3-months; antiplatelet therapy); three skin characteristics (pH upper extremities, SLEB upper extremities and skin thickness upper extremities); and a single skin property that were significantly associated with cutaneous manifestations of elastosis (collagen IV mean intensity upper extremities). Two of clinical variables identified in the

multivariable analysis were found not to be statistically associated with purpura in the univariable analysis. These clinical variables included antiplatelet therapy ($p = .091$) and SLEB upper extremities ($p = .920$).

A multivariable analysis of all individual characteristics, skin characteristics and skin properties that were identified to be significantly associated with purpura were performed after adjusting for potential confounding variables including age, gender, history of skin tears, history of falls and BMI. The results of this analysis are reported in Table 6.16.

Table 6.16. Multivariable Analysis (95% CI) of Baseline Variables in Participants with Purpura

Variables	Presence of purpura at baseline	
	OR (95% CI)	<i>p-value</i>
Precise age	1.08 (1.00–1.17)	.047
History skin tears previous 12-months		
No	1	
Yes	14.57 (5.18–40.93)	<.001
Falls in previous 3-months		
No	1	
Yes	2.89 (1.10–7.61)	.031
Antiplatelet therapy		
No	1	
Yes	3.40 (1.26–9.17)	.016
Mean skin surface pH forearms	4.42 (1.60–12.19)	.004
Mean SLEB forearms	1.01 (1.00–1.02)	.014
Mean skin thickness forearms	.99 (.99–1.00)	<.001

Note. OR = odds ratio; CI = confidence interval; SLEB = subepidermal low echogenicity band.

Multivariable analysis identified four individual characteristics (age, history of skin tears, history of falls, antiplatelet therapy) and three skin properties (pH, SLEB of the forearms, skin thickness) to be significantly associated with purpura. As the three skin properties were only significant at the dorsal forearm, a Pearson's Product-Moment Correlation Coefficient was conducted to better understand the relationship between all dorsal forearm baseline skin properties in participants with purpura. The results of this analysis are presented in Table 6.17.

Table 6.17. Pearson's Coefficient for Skin Properties and Purpura Dorsal Forearms

Purpura	Mean TEWL	Mean hydration	Mean pH	Mean SLEB	Mean thickness	Mean intensity	Mean VE	Mean distensibility	Mean retraction	Mean Type IV collagen	MMP-2 mean intensity
Hydration	-.288**										
Mean pH	.112	-.051									
Mean SLEB	-.004	.116	.006								
Mean thickness	.136	-.150	-.007	.645**							
Mean intensity	-.358**	.165	-.079	-.246*	-.305**						
Mean VE	-.249**	.287**	-.055	.122	.026	.099					
Mean distensibility	.216*	-.158	.082	.019	.212*	.038	.012				
Mean retraction	.316**	-.339**	.099	-.091	.005	-.229*	-.578**	.256**			
Mean type IV collagen	-.226*	.260**	-.247**	.089	.031	.155	.195*	-.020	-.081		
MMP-2 mean intensity	-.042	-.127	-.123	-.005	.067	.061	-.052	.113	.039	.197*	
TNF- α mean intensity	.263**	-.009	.126	.046	.067	.121	-.197*	.144	.119	-.298**	.013

Note. An asterisk (*) indicates a statistically significant difference, * = $p < 0.05$; ** = $p < 0.01$.

A moderately negative association ($p < .01$) was identified between: skin structural intensity and TEWL; skin structural intensity and skin thickness; and retraction and hydration in participants with purpura. A large negative association ($p < .01$) was found between retraction and VE. A moderately positive association ($p < .01$) was identified between retraction and TEWL in participants with purpura. A large positive association ($p < .01$) was identified between skin thickness and SLEB.

A Venn diagram was constructed to graphically illustrate the similarities and differences in individual characteristics, skin characteristics and skin properties that were significantly associated with the clinical characteristics manifestations of elastosis and purpura (Figure 6.3).

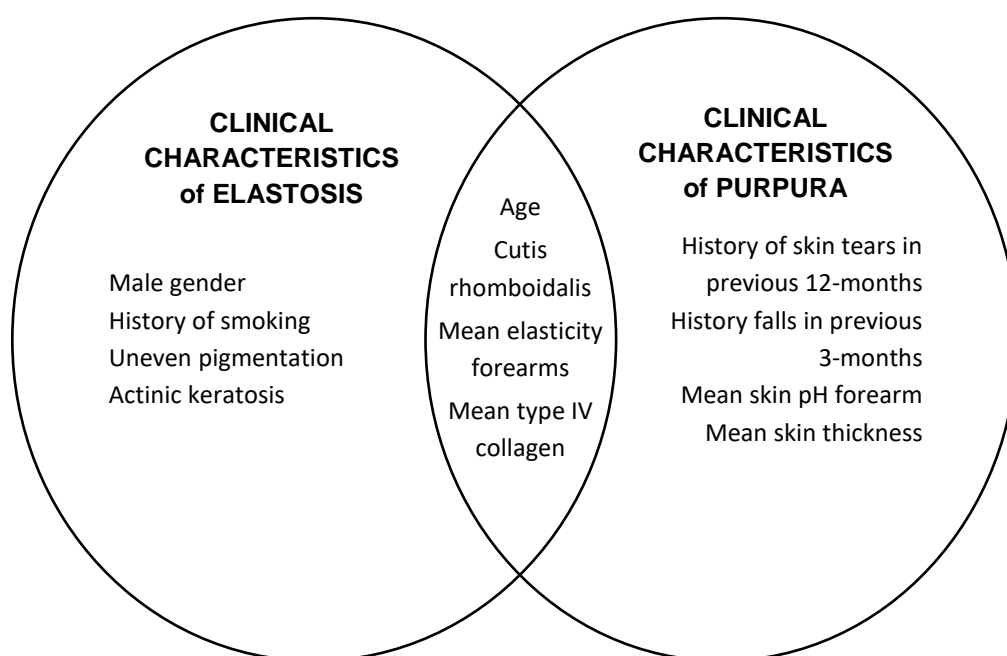


Figure 6.3. Venn diagram illustrating characteristics associated with cutaneous elastosis and purpura.

Variables that were significantly associated with both elastosis and purpura included age, cutis rhomboidalis, mean distensibility of the forearms and mean type IV collagen. Variables that were significantly associated with elastosis included male gender and factors that were primarily associated with extrinsic skin changes including: history of smoking, uneven pigmentation and AK. Conversely, variables that were significantly

associated with purpura related to two adverse events (history of skin tears or history of falls) and changes in skin properties (mean skin pH forearm or mean skin thickness).

6.4. Chapter Summary

The chapter presents the analysis conducted to investigate baseline individual characteristics, skin characteristics, and morphological and physiological skin properties variables that predicted the risk of skin tear at 6-months. Multivariable analysis identified five baseline characteristics (male gender, history of skin tears, history of falls, clinical elastosis, skin purpura), that significantly predicted the risk of skin tears at 6-months in this sample of aged care residents. The analysis did not identify any skin property that predicted the risk of skin tears at 6-months. Additional analysis conducted to investigate the relationship between the two skin characteristics and skin tears of the forearm identified a range of underlining skin properties that were statistically significantly associated with the cutaneous manifestations of elastosis (age, male gender, uneven skin pigmentation, cutis rhomboidalis nuchae, history of smoking, history of AK, collagen IV forearm) and purpura (age, history of skin tears, history of falls, antiplatelet therapy, skin pH, SLEB, skin thickness). A detailed discussion of the findings from this prospective study is presented in Chapter 7.

Chapter 7

Individual Characteristics, Skin Characteristics and Skin Properties Associated with Skin Tears: Discussion

This chapter discusses baseline individual (including demographics) characteristics, skin characteristics and morphological and physiological skin properties that were significantly associated with the skin tear occurrence at 6-months in relation to available evidence in the literature.

7.1. Variables Significantly Associated with Skin Tears.

Univariable analysis identified 34 variables that predicted the risk of skin tears. Subsequent multivariable analysis however, found only eight of these variables were significantly and independently associated with skin tears (Table 6.6). After adjusting for other explanatory variables multivariable analysis between baseline measurements and skin tears at 6-months identified five variables that were significant for predicting skin tears. These risk factors included male gender, history of skin tears in the previous 12-months, history of falls in the previous 3-months, cutaneous manifestations of elastosis, and skin purpura (Table 6.7). Additional analysis, found that some of the variables identified in the univariable analysis were associated with cutaneous manifestations of elastosis and purpura, which were two characteristics in the skin tear model.

In this resident aged care population, males were three times more likely to develop a skin tear compared to females. This result is similar to findings from a point-prevalence survey of skin tears conducted in a long-term care facility in Canada on 113 residents (LeBlanc et al., 2013). Two other studies, undertaken in long-term elderly Japanese residents, did not identify any significant difference between gender and the occurrence of skin tears (Koyano et al., 2014; Sanada et al., 2015). In male participants with skin tears the majority of injuries occurred on the upper extremities and in particular the right arm (Table 6.2).

The model identified two adverse events, including a previous history of skin tears and a previous history of falls that predicted the risk of skin tears. Participants with a history of skin tears were nearly four times more likely to develop a skin tear at 6-months. Three previous studies reported similar outcomes, but variation in their research design and the limited quantitative analysis did not permit further evaluation (McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; Skiveren et al., 2017). LeBlanc et al. (2013), however suggested a possible relationship existed between having a history of skin tears and the occurrence of skin tears. Further comparison with this study was limited by their point prevalence research design which recorded only a limited amount of information. A previous history of skin tears suggests that underlying changes to morphological and physiological properties of skin leave it vulnerable to repeat trauma related injuries.

Likewise, participants with a history of falls in the previous 3-months were more than three times more likely to develop a skin tear at 6-months. The identification of falls as an independent predictor of skin tears is perhaps not surprising since numerous studies of falls in older individuals show skin tears are a commonly reported injury that occur from this adverse event (Bank & Nix, 2006; Butler, Kerse, & Todd, 2004; Chang, Lin, & Chiang, 2015; Krauss et al., 2005; Resnick & Junlapeeya, 2004). Nonetheless, direct comparison with these studies was limited by the lack of their quantitative analysis and differences in research design. Not unlike a previous history of skin tears, the association between falls and skin tears suggests that in ageing skin underlying structural changes predispose some participants to increased risk of trauma related skin injuries.

The statistical model identified two clinical characteristics — cutaneous manifestations of elastosis and purpura — to be approximately three and three and a half times, respectively, more likely to be associated with an increased risk of skin tears. Cutaneous manifestations of elastosis in this study referred to the coarse, thickened, scaly, dry, and rigid texture that occurred across exposed skin surfaces (Patterson, 2016; Raimer et al.,

1986). Identification of clinical elastosis was made by comparing exposed skin surface to adjacent non-exposed skin sites. No previous study has reported textural skin changes from cutaneous manifestations of elastosis to be an independent risk factor for skin tears. Earlier work by Koyano et al. (2014) however, showed solar elastotic changes in the dermis, identified using 20-MHz ultrasonography to measure the SLEB, was a potential risk factor for skin tears. Textural changes with associated thickening of the dermis from concomitant loss of elasticity is reported to increase the risk of skin tears (Ling, 2010).

Purpura, in this prospective study, referred to the clinical manifestation of non-inflammatory and non-palpable ecchymotic lesions on the skin that ranged in size from between 2–20mm in diameter. Purpura has previously been reported to be associated with skin tears (White et al., 1994). Decreased amounts of collagen that support small blood vessels are reported to contribute to the risk of purpura (Gloster Jr et al., 2016; Leo & Sivamani, 2015).

7.2. Clinical manifestations associated with skin tears.

Multivariable logistic regression analysis identified a broad range of variables that were statistically significantly associated with the clinical skin manifestations of elastosis and purpura. Seven variables were identified to significantly predict cutaneous manifestations of elastosis (Table 6.11). These variables may be broadly classified as three individual variables (age, gender, smoking), three clinical (uneven skin pigmentation, cutis rhomboidalis nuchae, history of AK) factors, and one skin property (mean collagen type IV forearm). In relation to purpura, four individual (age, history of skin tears in the previous 12-months, history of falls in the preceding 3-months, taking oral antiplatelets) factors and three skin properties (mean pH of forearms, mean SLEB forearms, mean skin thickness of the forearms) were significantly associated with the occurrence of purpura (Table 6.16). Ageing was a common predictor of both clinical elastosis and purpura.

While not common to both manifestations, a range of skin properties that were specific to the upper extremities were implicated in their occurrence. The upper extremities were the skin sites where clinical manifestations of elastosis and purpura were more pronounced and where 58% of the skin tears occurred. The higher incidents of skin tears across the upper extremities was consistent with previous studies amongst aged care residents (Carville et al., 2014; LeBlanc et al., 2013; Malone et al., 1991; Sanada et al., 2015; White et al., 1994). The findings from the present study suggest that changes to underlying skin properties are indirectly implicated in the risk of skin tears at the upper extremities.

The upper extremities, together with the face and neck are skin sites with the greatest potential for exposure to UV radiation (Pastila, 2013). Vertical skin surfaces of an erect person have been reported to receive about 50% of ambient UV radiation, while horizontal surfaces receive as much as 75% (Diffey, 1991). It is possible that the dorsal surface of the upper extremities is also exposed to similar levels of UV exposure. While exposure of skin to UV radiation has a number of beneficial effects, chronic exposure can also have harmful effects. The beneficial effects of small amounts of UV exposure on skin surfaces includes Vitamin D synthesis, and at therapeutic concentrations is used in the treatment of several skin conditions including rickets, psoriasis and eczema (Juzeniene & Moan, 2012; World Health Organisation, 2002).

The harmful effects of photoaged-related degenerative changes impact on cellular, fibrous and vascular skin structures (Caetano, Soares, Bagatin, & Miot, 2015; Calderone & Fenske, 1995; Guimarães et al., 2015; World Health Organisation, 2002). The cumulative effects of UV radiation on exposed skin surfaces have been shown to clinically manifest as elastotic skin changes, purpura, uneven skin pigmentation as well as melanoma and non-melanoma skin lesions (Biniek, Levi, & Dauskardt, 2012; Friedman et al., 2016; Green, Hughes, McBride, & Fournier, 2011; Oba & Edwards, 2006; Rittié & Fisher, 2015; Varani et al., 2006; Yin, Chen, & Hamblin, 2015; Young, 2009).

In this study, participants with a skin tear incident reported significantly higher ($p < .001$) levels of exposure to UV radiation in the course of their previous occupation and recreational behaviours (Table 6.4). Male participants with skin tears reported significantly higher levels of exposure to UV radiation over the course of their life compared to female participants with skin tears. Males typically report experiencing higher amounts of exposure to UV radiation than females, although this difference is generally considered to be greater after the age of 20 years (Gies, Roy, & Udelhofen, 2004; Godar, Wengraitis, Shreffler, & Sliney, 2001; Mahler, Kulik, Gerrard, & Gibbons, 2013).

No further discussion was warranted concerning the lower extremities as there were no specific morphological or physiological skin property change that were either directly or indirectly associated with the risk of skin tears. A more detailed discussion of the clinical manifestations of elastosis and purpura is provided in the following text with the primary focus on the upper extremities, particularly the dorsal forearms.

7.2.1. Variables associated with elastosis of the forearms.

The clinical spectrum of cutaneous manifestations of elastosis is reported to differ between skin types, and the extent to which skin is subjected to UV radiation and sustains photoaged-related skin changes (Yaar, 2007). Lower Fitzpatrick skin types are well documented in the literature to be genetically more susceptible to cumulative effects of UV radiation and photoaged-related changes across exposed skin surfaces (Del Bino, Sok, Bessac, & Bernerd, 2006; Friedman et al., 2016; Gilchrest, 1989; Ueda, Matsunaga, Bito, Nikaido, & Ichihashi, 1996).

The logistic regression analysis in this prospective study identified seven variables that were statistically significant predictors for cutaneous manifestations of elastosis. This support the association between extrinsic ageing and clinical skin changes. Six of these variables were broadly categorised as genetic (ageing, male gender), environmental (uneven skin pigmentation, cutis rhomboidalis nuchae, presence of AK) and lifestyle

(history of smoking) related factors. The seventh variable, collagen type IV, was the only skin property identified to be directly associated with clinical elastosis.

In this study, age was associated with a 1.12 increased risk of participants sustaining cutaneous manifestations of elastosis (Table 6.11). Similar results were reported by Karagas et al. (2007) and Schäfer et al. (2006). Karagas et al. (2007) in a case-controlled study of 1,118 adults, aged between 25–74 years, reported males over 70 years had a 2.3 (CI 1.0–5.5) increased odds of developing severe elastosis across exposed skin surfaces whereas females of a similar age had a 5.0 (CI 2.0–13.5) increased odds. A survey and skin examination of 2,823 adults conducted by Schäfer et al. (2006) found that 93.8% of individuals aged between 65–74 years showed some degree of cutaneous elastosis. Both studies reported considerable inter-individual variation in the degree and extent to which elastotic skin changes occurred across photo-exposed skin surfaces.

The clinical manifestation of elastosis from aged-related and photo-aged related skin changes are induced from degenerative changes within the ECM of both the epidermis and dermis (Rittié & Fisher, 2015). In the epidermis, the ECM is the basement membrane whereas the ECM of the dermis comprised of fibrillar collagens and elastic fibres (Pittet, Freis, Vazquez-Duchêne, Périé, & Pauly, 2014; Watt & Fujiwara, 2011). The three main classes of biomolecules that form the ECM includes the structural proteins (collagen and elastic fibres), specialised proteins (fibrillin, fibronectin and laminin), and proteoglycans that are composed of glycosaminoglycans (GAGs) covalently attached to core proteins (Ladoux & Nicolas, 2012). Individually, these biomolecules provide cellular adhesion (fibrillin, fibronectin and laminin), resist tensile forces (fibrillar collagens), compressive forces (proteoglycans) and confer elasticity (elastic fibres) behaviours to the skin through their mechanical properties (Mellody, Bell, & Sherratt, 2016; Naylor, Watson, & Sherratt, 2011). The mechanical properties of skin are dependent on its structural properties, which determine its tensile strength, integrity and the

degree to which it can expand without tearing (Burrows & Lovell, 2010; Liang & Boppart, 2010; Payne, 1991).

Aged-related and photoaged-related skin changes have been shown to cause architectural and structural remodelling that alter the mechanical properties of the biomolecules and the gross appearance of skin (Ichihashi, Ando, Yoshida, Niki, & Matsui, 2009; Mellody et al., 2016). In the initial stages, photodamaged skin has an acanthotic or thickened appearance whereas in the later stages the skin appears thin and fragile from atrophic changes associated with a decline in cellular structures (Ippolito et al., 2012; Riahi, Bush, & Cohen, 2016).

The literature clearly demonstrates structural skin ECM proteins have a long lifespan and low turnover that predisposes them to modification from the cumulative and deleterious effects of time and UV radiation (Agache, Monneur, Lévêque, & Rigal, 1980; Escoffier et al., 1989; Muto, Kuroda, Wachi, Hirose, & Tajima, 2006; Naylor et al., 2011; Ritz-Timme, Laumeier, & Collins, 2003; Robert, Robert, & Fülöp, 2008; Smith Jr, Davidson, Sams Jr, & Clark, 1962; Thurstan et al., 2012; Warren et al., 1991). The half-life of skin collagen is estimated to be about 15 years whereas elastin is about 70 years (Shapiro, Endicott, Province, Pierce, & Campbell, 1991; Verzijl et al., 2000). The longevity of these ECM proteins makes them susceptible to the cumulative effects of ageing and UV radiation, which progressively degrade the dermal architecture of the skin to cause loss of functional structural skin proteins, altered biomechanical behaviour and gross clinical manifestations (Castanet & Ortonne, 1997; Griffiths, 1992; Han, Chien, & Kang, 2014; Verzijl et al., 2000).

The present study was undertaken in Western Australia, where the average outdoor worker in Perth is estimated to receive about three times (123 300 Joule/square metre (J/m^2)) the amount of UV exposure per year compared to an indoor worker (37 000 J/m^2) (Godar, 2005). The extent of exposure to UV radiation rises as life expectancy increases (Biniek, Kaczvinsky, Matts, & Dauskardt, 2015). Nearly 50% of UV exposure and

associated skin damage occurs within the first 20 years of an individual's life, with the initial 5 years of a child's life spent in geographical locations with long daylight hours contributing to the long-term risk of malignant and structural property skin changes (Green, Wallingford, & McBride, 2011; Hillebrand, 2010; MacKie, 2000). Incident and mortality data show that individuals with low Fitzpatrick skin types, who migrate from geographical regions of high latitude to a low latitude location before the age of 10 to 20 years, have higher levels of UV radiation exposure, skin changes and skin cancers than individuals who migrated as an adult (Le Marchand et al., 2006; Levine et al., 2013).

Examination of place of birth, which was based on the Australian Standard Classification of Cultural and Ethnic Groups (ASCCEG), showed that 90.6% of participants in the present study were born either in the Oceanian or the North-West Europe region (Australian Bureau of Statistics, 2011). Further evaluation of participants who were born in these regions was conducted to determine the influence that gender and number of years living in Australia had on the clinical manifestation of elastosis. The analysis showed that the median number of years that participants lived in Australia, based on geographical place of birth, ranged between 10–20 years longer for both sexes with cutaneous manifestations of elastosis than participants without these clinical signs.

Male participants in this study were more than three and a half times more likely to display clinical manifestations of elastosis than female participants (Table 6.11). This result is consistent with findings by Carey and Hogan (1990) and Hughes, Strutton, Fourtanier, and Green (2012). The inclusion of males in the statistical model suggests that male participants likely had higher levels of UV radiation exposure than female participants. Based on the age of participants it is conceivable that either gender was generally unaware of the risk of long-term exposure to UV radiation and typically did not engage in sun protective behaviours. Furthermore, sunscreen only became available for general use in Australia in the 1970s by

which time the impact of environmental exposure would have resulted in photoaged-related skin changes in this resident population (Aldahan, Shah, Mlacker, & Nouri, 2015; Garland, Garland, & Gorham, 1993).

Participants with a history of smoking were over two and a half times more likely to display clinical signs of elastosis than participants who did not smoke. This result is similar to previous findings indicating cigarette smoking is an independent risk factor for elastotic skin changes (Boyd et al., 1999; Kadunce et al., 1991; Kennedy et al., 2003). In the present study, 66.7% of males who had previously smoked displayed clinical manifestations of elastosis compared to 43.2% of females. Previous research showed smoking was strongly associated with the male gender and independent of UV exposure (De Hertog et al., 2001). Smoking by itself or in combination with UV exposure is a strong predictor of premature skin ageing (Leung & Harvey, 2002; Morita, Torii, Maeda, & Yamaguchi, 2009). Exposure to UV radiation and smoking have equally been shown to accelerate elastotic skin changes through thickening and destruction of elastic fibres by up-regulating MMPs involved in the synthesis of collagen and elastic fibres, and the degradation of proteoglycans (Boyd et al., 1999; Just, Ribera, Monso, Lorenzo, & Ferrandiz, 2007; Kennedy et al., 2003; Ortiz & Grando, 2012; Wolf, Wolf, & Ruocco, 1998). Skin changes associated with photo-ageing primarily affect the papillary dermis whereas smoking impacts on both the papillary and reticular dermis (Castelo-Branco & Davila, 2015).

Participants with cutis rhomboidalis nuchae were more than three and half times more likely to displays signs of clinical elastosis of the forearms compared to participants without this manifestation. Cutis rhomboidalis nuchae, a clinical variant of elastosis, was evident on the posterolateral aspect of the neck of 77.8% of males and 52.2% of females with elastotic skin changes of the dorsal forearm. Cutis rhomboidalis nuchae is specific to the nape of the neck and is a clinical sign of prolonged exposure to UV radiation (Patterson, 2016). It is predominantly seen in males from their characteristically shorter hair style (Bilaç, Şahin, & Öztürkcan, 2014;

Calderone & Fenske, 1995; Chen, Fleischmajer, Schwartz, Palaia, & Timpl, 1986). A pathological facet of cutis rhomboidalis nuchae is the deposition of anti-carboxymethyllysine antibody-positive substances in the middle to upper layers of the dermis from elastotic skin changes (Ichihashi, Yagi, Nomoto, & Yonei, 2011; Yonei, Takabe, & Yagi, 2015). Carboxymethyllysine (CML) is a major advanced glycation end product (AGEs) that accumulates within sun exposed skin and contributes to glycoxidation modification of longevity cells including ECM proteins (Gorisse et al., 2015; Sell et al., 1996).

The AGEs form from the non-enzymatic reaction between free amino groups in proteins and a reducing sugar, which induces a complex series of reorganisation and dehydration, and the formation of an irreversible cross-linked product (Paeon et al., 2013; Pennacchi et al., 2015). The harmful effects of AGEs are exerted both biologically and through interacting with specific receptors (RAGE), which have primarily been observed in the middle and basal zone of the epidermis and in the reticular dermal compartments of older skin from photoageing (Gkogkolou & Böhm, 2012; Lohwasser, Neureiter, Weigle, Kirchner, & Schuppan, 2006). The presence of RAGE-positive cells has shown to increase in the papillary dermis of photo-exposed skin surfaces compared with photo-protective skin surfaces (Lohwasser et al., 2006). Modification of longevity skin proteins from photoageing and the deleterious formation of cross-links can inhibit normal tissue function by causing the fibres to pathologically stiffen and become brittle (Avery & Bailey, 2005). These molecular changes conceivably have the potential to cause tearing and disruption to the integrity of skin tissue.

Participants with uneven skin pigmentation were eight times more likely to show clinical manifestations of elastosis than participants without pigmented skin changes. Uneven skin pigmentation was evident across resident's dorsal forearms and supports the literature findings that exposed skin surfaces exhibit greater irregularity of pigmentation from UV stimulation of melanocytes (Costin & Hearing, 2007; Ortonne, 1990). Research involving chronic sun-exposed skin surfaces demonstrate uneven skin pigmentation is

a clinical marker of photo-damaged skin, which increases with age (Rittié & Fisher, 2015).

A documented history of AK was associated with nearly three times increased risk of cutaneous elastosis compared to participants without a documented history. The AK occur from chronic keratinocyte damage through prolonged exposure to UV radiation (Bilaç et al., 2014). The statistically significant association between AK, photoageing and elastotic skin changes is consistent with previous studies (da Silva, Coelho, Lorenzetti Bocca, & Figueiredo Cavalcante Neto, 2007; Tsatsou, Trakatelli, Patsatsi, Kalokasidis, & Sotiriadis, 2012). Clinically, AK primarily occurs on sun-exposed skin surfaces of older individuals with low Fitzpatrick skin types and is considered a marker of photoageing as they are induced by cumulative exposure to UV radiation (Roewert-Huber, Stockfleth, & Kerl, 2007; Schiller, Nashan, & Sunderkötter, 2009). Regardless of gender, participants exhibiting clinical manifestations of elastosis of the dorsal forearm were significantly ($p < .001$) more likely to have a documented history of AK than participants without a history of AK (Table 6.8).

Participants with higher type IV collagen levels were associated with a 1.05 significant increased risk for cutaneous manifestations of elastosis compared to participants with a lower collagen type IV levels. Type IV collagen is a ubiquitous, network forming extracellular basement membrane protein that is synthesised in the skin by epidermal keratinocytes and dermal fibroblasts (Betz et al., 1992; Breitkreutz, Koxholt, Thiemann, & Nischt, 2013; Harvey & Thorner, 2005; Timpl, 1989; Tobin, 2017). Collagen type IV is the principle component of the DEJ junction and provides mechanical stability and structural support to the skin (Abreu-Velez & Howard, 2012; Betz et al., 1992; Breitkreutz et al., 2013; Halfter et al., 2015; Harvey & Thorner, 2005; Timpl, 1989; Tobin, 2017). Microscopically, the basement membrane forms a thin mesh-like extracellular sheath that physically separates the epidermis from the dermis to maintain dermal-epidermal integrity under mechanical stress (Breitkreutz et al., 2013; Pöschl et al., 2004; Wiradjaja, DiTommaso, &

Smyth, 2010). The basement membrane forms rete pegs and ridges that appear as an undulated line when viewed in a planar cross section (Yannas, 2015). This mesh-like structure provides flexibility and extensibility and is a major regulator of tissue stiffness (Akhmanova, Osidak, Domogatsky, Rodin, & Domogatskaya, 2015; Candiello et al., 2007; Candiello, Cole, & Halfter, 2010; Halfter et al., 2015; Miner, 2010).

Higher levels of type collagen IV in the skin have been associated with increased thickening of the basement membrane (Kahan, Andersen, Tomimori, & Tufik, 2009; Paeon et al., 2015). Contemporary research indicates that excess production of collagen type IV and the concomitant thickening of the basement membrane are influenced by both ageing and chronic UV exposure, through the glycation of longevity dermal ECM proteins (collagen and elastic fibres) and the accumulation of cytotoxic AGEs (Gendron & Rochette, 2015; Gkogkolou & Böhm, 2012; Lohwasser et al., 2006; Paeon et al., 2015). Glycation occurs between intracellular and extracellular proteins and sugars post-translationally (proteins that are modified during or following their biosynthesis), by a non-enzymatic Maillard reaction which is essential for normal protein repair and tissue remodelling (Gkogkolou & Böhm, 2012; Paeon et al., 2013).

Longevity proteins are particularly vulnerable to modification by the cytotoxic accumulation of AGEs (Larsson, Favilla, & Strömberg, 2016; Verzijl et al., 2000). A biomarker of protein glycation, CML, occurs in photo-exposed skin sites and suggests UV-generated oxidation may accelerate AGEs formation (Crisan et al., 2013). The AGEs act as a biological sensitiser for photo-oxidative cell impairment by UV-generated reactive oxygen species (ROS) to influence skin photoageing, photocarcinogenesis, and the reduction in digestible matrix (Crisan et al., 2013; Paeon et al., 2013; Wondrak, Roberts, Jacobson, & Jacobson, 2002). The accumulation of cytotoxic AGEs alters skin biomechanical properties through cross-linking of adjacent collagen fibres, increased tissue stiffness, reduced skin elasticity, loss of skin plasticity, reduced susceptibility of MMPs to regulate protein renewal, and

impaired lateral extensibility that decrease the resistance of collagen to mechanical forces (Gkogkolou & Böhm, 2015; Halfter et al., 2015; Nowotny & Grune, 2014; Paegeon et al., 2015).

The findings of this prospective study suggest an indirect association between increased collagen type IV and skin tears. This result differs to the initial work by Koyano et al. (2014) identifying decreased collagen type IV was directly associated with skin tears in a small sample of ageing Japanese. A later study by Koyano et al. (2017) however, failed to identify any association between type collagen IV and skin tears.

The difference in collagen type IV levels and the risk of skin tears between the two studies suggests that the two study samples differed in terms of the influence that chronological ageing, skin photoageing, environmental exposure and lifestyle behaviours had on the structural integrity and mechanical properties of skin. The risk of skin tears and differences in clinical manifestations may relate to the degree and extent to which skin is subjected to these influences, which may explain the different skin tear incident rates reported between Australian (40.6–59.4%) and Japanese (3.8–14.1%) aged populations (Carville et al., 2014; Everett & Powell, 1994; Koyano et al., 2014; Koyano et al., 2017; Sanada et al., 2015).

Seven variables (age, male gender, uneven skin pigmentation, cutis rhomboidalis nuchae, history of smoking, presence of AK, and type collagen IV) were identified in the present study to be statistically associated with the clinical manifestations of elastosis of the dorsal forearm. The findings from this study are consistent with the compelling body of evidence that shows a correlation between photoageing, lifestyle factors and age-related skin changes (Bilaç et al., 2014; Boyd et al., 1999; Braun-Falco, Plewig, Wolff, & Burgdorf, 2000a; Hughes et al., 2012; Kvaskoff et al., 2015; Leung & Harvey, 2002; Marshall, 1965).

7.2.1.1. *Skin properties associated with elastosis of the forearms.*

An independent *t*-test was conducted to better understand the differences in morphological and physiological skin properties between participants with and without cutaneous manifestations of elastosis (Table 6.9). This analysis identified five skin properties including collagen type IV, TEWL, hydration, distensibility, and retraction that statistically significantly differed between participants with and without clinical elastosis of the forearm. A Pearson's Product-Moment Correlation Coefficient was subsequently performed to understand the relationship between all skin properties in participants with clinical manifestations of elastosis of the dorsal forearms (Table 6.12). These findings are discussed in greater detail in the following section.

7.2.1.1.1. *Collagen type IV.*

Participants with cutaneous manifestations of elastosis had significantly higher levels of type IV collagen. Higher levels of type IV collagen were statistically significantly negatively correlated with lower skin pH. While the precise reason for this association is unknown, the decline in skin surface pH may reflect changes to the structural components of the skin in participants with elastotic skin manifestations.

7.2.1.1.2. *TEWL.*

The mean TEWL across all extremities was significantly higher in participants with clinical manifestations of elastosis compared with participants without elastosis. The TEWL relates to the diffusion of insensible water loss from the skin surface without the influence of active sweating (Fluhr & Darlenski, 2014; Rogiers, 2001). The measurement of TEWL is considered a surrogate means for evaluating the effectiveness of the skin barrier and is an indirect indicator of the integrity of the SC function (Imhof & McFeat, 2014). The skin barrier is regulated by the level of SC water content with higher skin hydration contributing to a decline in TEWL and suggests a more intact and effective skin barrier (Trojahn, Dobos, Blume-Peytavi, & Kottner, 2015). Measurement of the TEWL is considered a convenient

method for identifying skin damage as measurement levels increase in proportion to the degree of impairment (Roelandt, Roseeuw, & Hachem, 2011). Conversely, the measurement of hydration assesses the structural and behavioural integrity of skin as water is bound to the proteoglycans, which in turn influences the VE properties of skin (Rawlings & Harding, 2004).

The higher TEWL and lower hydration readings obtained across the dorsal forearm of participants with clinical skin elastosis suggests a degree of disruption to the skin barrier. This result is similar to findings of previous studies which show photoageing alters the permeability function of the skin barrier across exposed skin surfaces (Haratake, Uchida, Mimura, Elias, & Holleran, 1997; Holleran et al., 1997; Meguro, Aral, Masukawa, Uie, & Tokimitsu, 1999). More recently, Blaak, Lüttje, John, and Schürer (2011) reported the TEWL of the exposed dorsal forearm of older individuals (mean age 82 ± 5 years) to be significantly higher than the non-exposed medial upper arm. Nevertheless, research relating to TEWL in the aged is conflicting with a number of studies reporting that it decreases after the age of 60-years and that the decline can be attributed to a compensation mechanism of the barrier function, decreased epidermal hydration content, decreased sweating or reduced microcirculation (Cua, Wilhelm, & Maibach, 1990; Elias & Ghadially, 2002; Wilhelm et al., 1991). In the present study, a small but positive correlation ($r(171) = .209, p = .006$) was found between age and TEWL of the dorsal forearms. Given that age only accounted for 4.4% of the variation in the TEWL result it is conceivable that the higher TEWL levels may well relate to morphological and physiological property changes to the skin barrier from photoageing.

Pearson's Product-Moment Correlation Coefficient also recorded a moderate inverse relationship between TEWL and hydration ($r(69) = -.332, p = .05$) in participants with elastotic skin manifestation of the dorsal forearms (Table 6.12). Recent research involving the repeated exposure of human skin samples to UV radiation reported a similar result with TEWL increasing as

the skin moisture content declined (Tian et al., 2014). These physiological property changes support the premise that in participants with clinical elastosis of the dorsal forearm the integrity of the skin barrier was diminished compared to participants without clinical elastosis.

7.2.1.1.3. *Hydration.*

The mean hydration of the dorsal forearm was significantly lower ($p = .002$) in participants with cutaneous manifestations of elastosis ($M = 69.23$, $SD = 30.18$) compared to participants without elastosis ($M = 84.35$, $SD = 31.23$). The DermaLab Combo® pin probe utilises the conductivity method to evaluate hydration by indirectly measuring the SC water binding capacity. Corneocyte hydration contributes to effective skin barrier function by conferring suppleness, elasticity, flexibility, plasticity and softness, which in turn bestows tensile strength to withstand deformation and tearing when under mechanical stress (Forslind, Engström, Engblom, & Norlén, 1997; Fowler, 2012; Piérard, 1989; Piérard, Hermanns-Lê, Paquet, & Piérard-Franchimont, 2014).

Optimal hydration is dependent on the structure, composition and organisation of the lipids within the ECM and the natural moisturising factors (NMF) of the skin (Fowler, 2012; Rawlings & Matts, 2005). The lipid layer, through its barrier function, is central for maintaining skin hydration and preventing water loss. Conversely, NMFs comprise amino acids, lactic acid, urea and sugars that endow a hygroscopic quality to the integumentary system (Kroll, Hoffman, Cunningham, & Koenig, 2012). The NMFs are the skin principal humectant with the hygroscopic ability to bind and retain water in the SC thereby preserving the elasticity and mechanical strength of the epidermis (Watabe et al., 2013). The water content of the SC is highly sensitive to the influences of environmental temperature, relative humidity and topical moisturisers (Anderson, Cassidy, Hansen, & Yellin, 1973; Kasting & Barai, 2003; Tagami, 2008). Adherence to the research protocol (Appendix F) helped to ensure the results were reliable and not influenced by these factors.

The lower hydration level findings for the dorsal forearm in participants with clinical manifestations of elastosis is consistent with previous studies that examined photoaged skin surfaces (Blaak et al., 2011; Kambayashi, Otake, Takada, Funasaka, & Ichihashi, 2003; Kikuchi-Numagami et al., 2000; Meguro et al., 1999). A small negative statistically significant association was found in the present study between hydration and skin surface pH, $r(71) = -.252$, $p = .05$, across the dorsal forearm (Table 6.12). Increased skin surface pH is associated with reduced hydration as lipid processing is controlled by the acidity level of the ECM (Mauro et al., 1998). Lipid hydrolases diminishes as skin surface pH increases to compromise the homeostatic function of the epidermal barrier (Mauro et al., 1998). Increased skin surface pH activates proteases that degrade corneodesmosomes to further disrupt the integrity of the SC (Behne et al., 2002; Hachem et al., 2003).

The dermal contentment of GAGs diminishes with age to alter both hydration and the mechanical properties of skin (Brown, Vural, Johnson, & Trinkaus-Randall, 1994; Lapière, 1990). While the level of GAGs is reported to increase in photoaged skin compared to chronologically aged skin they are disproportionally amassed on the elastotic material rather than generally distributed (Bernstein, Underhill, Hahn, Brown, & Uitto, 1996; Gniadecka et al., 1998). The accumulated GAGs bind weakly with water molecules and contributes to the increased amounts of unbound water in the dermis and the typically dry and furrowed appearance that is characteristic of photoaged skin (Bergman et al., 2015; Waller & Maibach, 2006).

7.2.1.1.4. Distensibility and retraction.

The elastic suction probe measured three variables: distensibility, retraction and VE. The mean skin distensibility and retraction time of the dorsal forearms significantly differed between participants with cutaneous manifestations of elastosis compared with participants without elastosis. In participants with clinical elastotic skin the mean distensibility values were increased, indicating skin was stiffer compared to participants without

elastotic skin manifestations. Likewise, the mean retraction was delayed (as indicated by increased values) in participants with clinical signs of elastosis compared to participants without cutaneous manifestations of elastosis. The reduced distensibility and delayed retraction (recoil) time for participants with cutaneous manifestations of elastosis compared with participants without elastosis suggests some loss of functionality. This result is similar to the findings of previous studies that showed delayed skin distensibility and retraction is related to photoaged-related skin changes (Bazin, Laquière, Rosillo, & Lévêque, 2010; Griffiths, 1992; Richard, de Rigal, de Lacharriere, Berardesca, & Lévêque, 1994). Based on their findings, Corstjens et al. (2008) conjectured that AGEs contributed to the gradual decline in skin elasticity and resultant loss of mechanical properties in individuals as they aged. Other studies have shown that photoageing is responsible for ECM structural and elastotic skin changes and the concomitant modification to the mechanical properties of skin (Chen et al., 1986; Paegeon, Técher, & Asselineau, 2008; Schwartz, Cruickshank, Christensen, Perlish, & Lebowitz, 1993).

The measurement of VE in the present study was not directly associated with clinical elastosis of the dorsal forearms. VE measures the ability of skin to deform under stress and resume its initial shape by evaluating both its elastic and viscous behaviour (Everett & Sommers, 2012; Silver et al., 2001). Skin VE behaviour involves conformational change and the capability of structural proteins to slide or creep during deformation that protect the skin from mechanical stress and then return to its natural shape (Naylor et al., 2011; Ruvolo Jr, Stamatas, & Kollias, 2007; Silver, 2006). Research has shown that high hydration levels permit skin to exhibit greater viscoelastic behaviour while lower levels reduce the distension or extent of the creep response (Edwards & Marks, 1995; Everett & Sommers, 2012). Previous research evaluating the suction probe method has shown that it is not an effective means for evaluating skin surfaces with a rigid texture (Vexler, Polyansky, & Gorodetsky, 1999). The failure to identify any statistically significant association between VE across the dorsal forearm in participants

with cutaneous manifestations of elastosis may reflect the extent of skin photoageing and the associated pathological changes to connective tissue exhibited by participants in this study.

A moderate positive correlation, $r(71) = .348$, $p = .01$, was identified however, between mean VE and type IV collagen in participants with clinical elastosis of the dorsal forearms (Table 6.12). This finding suggests that in participants with clinical elastosis, increased type collagen IV inhibits the viscoelasticity behaviour of skin. As previously discussed, collagen type IV is a major component of the basement membrane of the DEJ and a regulator of skin stiffness. Logistic regression had earlier shown that higher collagen type IV levels were associated with an increased risk for clinical elastosis of the forearm compared to skin without elastotic skin manifestations. Photoageing and associated elastotic skin changes have histologically been likened to fibrotic tissue (Lavker, 1979; Montagna, Kirchner, & Carlisle, 1989). Recently, similar research involving systemic sclerosis found that increased VE was an early sign of fibrotic skin changes, a common skin characteristic for this condition (Dobrev, 2013). The positive correlation between VE and type IV collagen reaffirms that in the present study, the skin of participants with clinical elastotic skin exhibited a degree of rigidity.

7.2.1.1.5. SLEB, skin thickness and skin intensity score.

The SLEB is considered an objective biological marker for quantifying skin photoageing as its thickness and density increases proportionally with age and exposure to UV radiation (Richard et al., 1994; Sandby-Møller & Wulf, 2004). Ultrasound imagery show the SLEB appears as a delimited hypo-echogenicity band (Figure 3.4) in the papillary dermis (Gniadecka, 2001; Wortsman, 2016). The SLEB is reported to correspond to the formation of non-functional elastotic material and arises when elastin and GAGs accumulate in the papillary dermis (Burrows & Lovell, 2010; Knott et al., 2009; Micali et al., 2011). The thickness of the SLEB increases with age and the proportion of skin photoageing, and has been established to be more

pronounced across the dorsal forearm (de Rigal et al., 1989; Gniadecka & Jemec, 1998; Jasaitiene et al., 2011; Micali et al., 2011).

While descriptive analysis showed the mean SLEB ($M = 296.9$, $SD = 89.3$) was higher in participants with clinical signs of elastosis compared to participants without visible manifestations ($M = 285.2$, $SD = 79.7$) of elastosis, the independent t -test found they were not significantly ($p = .370$) different. The analysis also yielded no significant correlation between age and the SLEB, $r(69) = .153$, $p = -.171$, in participants with clinical elastosis of the forearm. Similarly, descriptive analysis showed a non-significant mean difference ($p = .205$) between skin thickness ($M = 845.8$, $SD = 179.0$) of the dorsal forearms in participants with clinical signs of elastosis compared to participants without visible manifestations ($M = 810.3$, $SD = 181.1$) of elastosis.

A Pearson's Product-Moment Correlation Coefficient, $r(69) = .529$, $p = <.01$, demonstrated a moderate positive correlation between the mean skin thickness of the dorsal forearms and the mean SLEB in participants with elastotic skin manifestation (Table 6.12). The DermaLab® Combo measures total skin thickness from the epidermis to the dermal-hypodermis interface (Figure 3.4) and includes the SLEB (Seidenari, 2006; Waller & Maibach, 2005). The positive correlation between skin thickness and the SLEB across the dorsal forearm is consistent with previous findings showing the width of the SLEB reflected the magnitude and severity of skin photoageing (Giusti & Seidenari, 2010; Gniadecka & Jemec, 1998; Marks & Edwards, 1992). This result suggests that in this resident population photo-related skin changes may have had a greater influence on the formation of the SLEB and concomitant increase in skin thickness than age-related skin changes.

The mean intensity score was not significantly different between participants with and without elastotic skin manifestations of the dorsal forearm. Nevertheless, the lower mean intensity value in participants with clinical elastosis compared to participants without elastosis suggests there may be some loss in skin collagen.

7.2.1.2. *Summary of elastotic skin changes of the dorsal forearm.*

Cutaneous manifestation of elastosis of the dorsal forearm was associated with photoaged related skin changes and increased skin stiffness. Photoaged related skin changes manifested on exposed skin surfaces to alter the underlying mechanical properties, increase skin stiffness and contributed to the risk of skin tears from loss of tissue flexibility. The identification of cutaneous manifestation of elastosis appears to be a significant predictor of skin tears. This finding suggests that cutaneous manifestations of elastosis is a promising clinical risk factor, which can easily be assessed at the bedside for the immediate identification of individuals at risk of skin tears.

7.2.2. Variables associated with forearm purpura.

Multivariable logistic regression analysis identified seven variables that were statistically significantly associated with clinical skin purpura in this sample of residents. These variables included ageing, history of skin tears in the previous 12-months, history of falls in the preceding 3-months, taking antiplatelet medication, pH of forearms, SLEB of forearms, and decreased skin thickness of the dorsal forearms (Table 6.16). These variables can be categorised as chronological (ageing), adverse events (history of skin tears in the previous 12-months, history of falls in the preceding 3-months), medicinal (taking antiplatelet therapy) and skin properties (pH of dorsal forearms, SLEB of dorsal forearms, decreased skin thickness of the dorsal forearms).

In the present study, age was associated with a 1.08 increased risk of participants having purpura of the dorsal forearms. This result is consistent with the dermatological literature where purpuric lesions have been shown to occur on the extensor forearms and dorsal hands secondary to ageing, chronic UV exposure and some medications including antiplatelet medication or long-term corticosteroids (Arya, Gascon, & Kihiczak, 2002; Braun-Falco, Plewig, Wolff, & Burgdorf, 2000b; Chiriac et al., 2014; Daza & Jemec, 2013; Gloster Jr et al., 2016; Hampton, 2006; Kitchens, 2013; Trozak, Teenenhouse, & Russell, 2006). Globally, the incidents of purpura are

reported to range between 2% at age 70 years and 25% for centenarians (Beauregard & Gilchrest, 1987; Smith & Leggat, 2005; Tattersall & Seville, 1950).

Participants with a history of skin tears within the previous 12-months were 14 times significantly more likely to have purpura of the dorsal forearms compared to participants without a history of skin tears. Likewise, a history of falls in the previous 3 months was associated with nearly three times increased risk of purpura compared to participants who did not have a fall. Falls in older individuals have been implicated in the literature with the cutaneous manifestations of purpura and ecchymosis, loss of skin integrity, skin tears, lacerations and abrasions (Health Quality Ontario, 2008; Hitcho et al., 2004; Krauss et al., 2005; Ku et al., 2013). In spite of a paucity in the literature about the precise association between skin tears, falls and purpura it is conceivable that changes to morphological and physiological skin properties contribute to reduced resistance of tissue to mechanical forces.

Participants taking antiplatelet therapy in this study were nearly three and a half times more likely to display purpura compared to participants not taking this medication. Antiplatelet therapies exert their influence by interfering with the clotting process with the concomitant hypercoagulation state predisposing older individuals to such adverse skin manifestations as purpura and ecchymosis (Baker & Moore-Robinson, 1970; Bassas, Bartralot, & García-Patos, 2009; Hass et al., 1989; Litt, 2009; Taylor & Blatt, 1981; Thornsberry, LoSicco, & English III, 2013).

Participants with a higher skin surface pH of the dorsal forearms were nearly four and a half time significantly more likely to have purpura compared to participants with a lower skin pH. Measurements of skin surface pH have demonstrated to be a reliable method for evaluating the physical and biochemical effectiveness of the skin barrier (Nasir, 2010). Increased skin surface pH has been shown to correlate with impaired skin barrier function in individuals aged over 80 years and in photoaged skin (Biniek et al., 2012; Thune, Nilsen, Hanstad, Gustavsen, & Lövig, 1988; Waller & Maibach, 2005;

Wilhelm et al., 1991; Zlotogorski, 1987). The skin barrier function is optimal at a skin surface pH of about 5.5 with more neutral levels activating proteases that degrade the cohesive corneodesmosomes and disturb the normal processing of SC lipids (Barland & Ghadially, 2005; Blaak et al., 2011; Hachem et al., 2003; Haftek, 2015; Lambers, Piessens, Bloem, Pronk, & Finkel, 2006). Bioengineering research has shown that chronic UV radiation impairs the skin barrier by reducing intercellular strength, cohesion and integrity of intercellular lipids and corneodesmosomes to decrease the skins ability to withstand mechanical forces (Biniek et al., 2012; Pedersen & Jemec, 2006). No previous study was found that directly evaluated skin surface pH and purpura. Purpura however, may have indirectly been evaluated in these studies as it is a common skin manifestation reported to be associated with UV exposure (Cox & Piette, 2010; Joshi, Phadke, Khopkar, & Wadhwa, 1996; Kitchens, 2013).

A thicker SLEB of the dorsal forearm was associated with 1.01 significantly higher risk of purpura compared to participants with a thinner SLEB. As previously discussed the SLEB is associated with aged-related and photoaged-related skin changes (Richard et al., 1994; Sandby-Møller & Wulf, 2004). The SLEB is considered a biological marker for collagen degeneration of the papillary dermis and a reliable indicator of age and elastotic skin changes (Crisan, Badea, Cattani, & Crisan, 2012; de Rigal et al., 1989; Fligiel et al., 2003; Gniadecka, Gniadecki, et al., 1994; Gniadecka & Jemec, 1998; Lacarrubba, Tedeschi, Nardone, & Micali, 2008; Sandby-Møller & Wulf, 2004; Wortsman, 2016). Research by Sandby-Møller, Thieden, Philipsen, Schmidt, and Wulf (2004) demonstrated that UV radiation was a stronger influence of dermal echogenicity and the formation of the SLEB on exposed skin than chronological ageing.

For ease of interpretation the odds ratio of skin thickness was inverted as it was significantly but negatively associated with skin tears. The results suggest that as the thickness of skin declined there was 1.01 increased odds for purpura of the dorsal forearms. Other investigators have reported similar

findings (de Rigal et al., 1989; Gniadecka & Jemec, 1998; Hoffmann et al., 1994; Kligman & Lavker, 1988; Lasagni & Seidenari, 1995; Mathews, 1975; Richard et al., 1994; Shuster, Black, & McVitie, 1975). Skin thickness relates directly to the proportion of dermal collagen, elastin and GAGs (Kusuma, Vuthoori, Piliang, & Zins, 2010). Chronological and skin photoageing processes contribute to decreased skin thickness through reduced synthesis of procollagen I and III (Cox & Piette, 2010; Kammeyer & Luiten, 2015; Rittié & Fisher, 2015). The loss of structural collagen reduces the skin's mechanical supporting properties, leaving it vulnerable to trauma (Moronkeji & Akhtar, 2015). Decreased dermal collagen is associated with reduced scaffold support for small blood vessels that predispose them to rupturing, even from minor trauma (Cox & Piette, 2010; Kitchens, 2013).

7.2.2.1. Skin properties associated with forearm purpura.

An independent *t*-test was conducted to examine the influence that ageing skin properties had on the clinical manifestation of purpura to the dorsal forearms (Table 6.14). The analysis identified five skin properties including skin surface pH, skin thickness, distensibility, type IV collagen and MMP-2 that differed significantly between those participants with clinical purpura and participants without purpura of the dorsal forearm. A Pearson's Product-Moment Correlation Coefficient was performed to further investigate the relationship between all skin properties in participants with purpura of the dorsal forearms (Table 6.17).

7.2.2.1.1. pH.

As Section 7.2.2 provides a detailed discussion on the higher odds associated with increased skin surface pH and purpura of the dorsal forearm in participants of this study, the following discussion will focus briefly on the findings from the Pearson's correlation. The correlation identified a small negative correlation between increased skin surface pH and decreased type IV collagen, $r(106) = -.247, p < .01$) in participants with clinical purpura of the dorsal forearms (Table 6.17). The skin surface pH rises with both ageing and the influence of photoageing (Al-Nuaimi, Sherratt, & Griffiths, 2014; Tian et

al., 2014). The rising skin surface pH suggests a degree of collagenase degradation of ECM (Reynolds, 1996). The degradation of the ECM and presumably the basement membrane, which results in loss of structural proteins increases the risk of purpura. However, the precise relationship between increased skin surface pH and decreased type IV collagen in participants with purpura of the dorsal forearm needs further investigation.

7.2.2.1.2. *Distensibility.*

The mean skin distensibility differed significantly between participants with purpuric lesions of the dorsal forearm compared to participants without purpura. A small positive correlation, $r(106) = .212, p < .05$, was found between distensibility and skin thickness (Table 6.17). Participants with purpura of the forearm had significantly decreased skin thickness ($p < .01$) and significantly more rapid distension compared to participants without purpura (Table 6.14). The increased distensibility suggests underlying loss of structural collagen support, increased susceptibility to purpura, and changes to the mechanical properties of skin of the dorsal forearms that may be associated with the increased risk of skin tears across the extensor surface of the upper extremities. Changes in skin distensibility and the decrease in skin thickness is consistent with the findings of previous research (Diridollou et al., 2001). Both aged-related and photoaged-related skin changes have been reported to decrease the mechanical stability properties of skin by reducing the skin elasticity (Escoffier et al., 1989; Richard et al., 1994).

A positive correlation, $r(106) = .216, p < .05$, was found between distensibility and TEWL (Table 6.17). Increased TEWL is associated with altered skin barrier function while increased distensibility and loss of elasticity suggests a decline in connective tissue elastin. The increased distensibility and marked tissue displacement, which characterises ageing skin, could adversely decrease the skin's ability to resist frictional and shearing forces (Diridollou et al., 2001; Gerhardt et al., 2009; Piérard-Franchimont et al., 1999). These physiological changes have the potential to lead to purpura and a predisposition to skin tears.

7.2.2.1.3. *Collagen Type IV, MMP-2 and TNF- α .*

The mean collagen type IV and MMP-2 levels were significantly lower in participants with purpuric lesions compared with participants without purpura (Table 6.14). As discussed previously, type IV collagen is a ubiquitous collagen associated with the basement membrane of both skin and blood vessels (Candiello et al., 2010). The decline in collagen type IV suggests loss of stability and functional integrity of the vascular basement membrane with concomitant extravasation of blood into the dermal space in participants. Conversely, MMP-2 is a collagenase that catalyses type IV collagen (Ricard-Blum, 2010). Research into MMP-2 has shown that increased levels are associated with the degradation of elastin and basement membrane across exposed skin surfaces (Pinnell, 2003; Wlaschek et al., 2001). The MMPs function at more neutral pH levels to hydrolyse ECM proteins (Reynolds, 1996). Type collagen IV collagen is initially catalysed by MMP-2 with further degradation completed by other proteolytic enzymes (Kahan et al., 2009). However, MMP-2 inhibits dermal collagen synthesis which results in loss of skin elasticity and flexibility (Raschke & Elsner, 2010; Rojo et al., 2013). The precise reason for the lower level of MMP-2 across the dorsal forearm in participants with purpura compared to participants without purpura, is unclear and needs further investigation. Nevertheless, it may reflect or be in response to the decline in capillary type IV collagen identified in the present study. Previous research into MMP-2 has principally focused on dermal collagen with no reported studies identified that directly examined the relationship between MMP-2 and clinical purpura.

A Pearson's correlation demonstrated a negative correlation between collagen type IV and TEWL ($p = <.05$) and with pH ($p = <.01$). A positive correlation was noted between type IV collagen and hydration ($p = <.01$) and with VE ($p = <.05$). These findings show the overall interaction between the various skin properties and the decline in the skin barrier function and hydration status of ageing skin. In spite of a Pearson's correlation showing a correlation between TNF- α , TEWL, VE and collagen type IV (Table 6.17) an independent-samples t -test did not identify any significant difference ($p =$

.118) between participants with and without purpura for these variables (Table 6.14).

7.2.2.2. *Ecchymotic skin lesions and the forearms.*

Purpuric and ecchymotic skin lesions have previously been reported to be associated with skin tears (McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; White et al., 1994). These benign lesions are principally confined to the dorsal hands and the extensor surface of the dorsal forearms (Chiriac et al., 2014; Norman & Young, 2014). The aetiology of both lesions is reported to arise from increased fragility of blood vessels and a decline in dermal structural collagen, from aged-related and photoaged-related skin changes, which impact on the mechanical integrity of skin (Cox & Piette, 2010; Husain et al., 2011).

Despite the univariable analysis showing that both purpuric and ecchymotic lesions were significantly associated with skin tears, multivariable analysis only added purpura to the skin tear model (Table 6.7). The addition of purpura to the statistical model may reflect the age of the study population, which ranged from 65–107 at time of the initial assessment, and the large degree of inter-individual variability in clinical skin manifestations. It is conceivable that purpura may be an early clinical manifestation of changes to the physiological skin properties compared to ecchymosis, where clinical manifestations are more extensive.

In the present study, the majority of purpuric lesions were visible over the dorsal forearms while more extensive ecchymotic lesions were observed over the dorsal hand and wrist. Anatomically, the skin of the dorsal hand is thin and flexible and is attached to the underlying skeleton by loose areolar (collagen, elastic, reticular fibres and GAGs) tissue and thin hypodermal tissue (Langevin, Nedergaard, & Howe, 2013; Wilhelmi, 2016). The structure of areolar tissue differs from other connective tissues as it is principally non-load bearing and behaves as an interface to permit sliding of adjoining connective tissues (Abbott et al., 2013).

Areolar tissue consists of loose, irregularly arranged connective tissue comprising of collagen fibres, elastic fibres, reticular fibres and glycosaminoglycans (GAGs) (Langevin et al., 2013). The structural arrangement of skin and subcutaneous tissue may explain why ecchymotic lesions appear to be more pronounced and more evident in this study across the hands and wrist compared to the forearms. Further investigations are needed to determine the extent to which structural dermal collagen changes contribute to the clinical manifestations of purpura and ecchymosis and skin tears in older individuals.

7.2.2.3. *Summary of purpura of the dorsal forearm.*

Purpuric lesions of the dorsal forearm were associated with aged related skin changes and decreased skin thickness possibly from loss of dermal collagen. The reduction in skin thickness most likely impaired the skin's structural integrity and ability to resist mechanical forces and contributed to the risk of skin tears. This finding suggests that purpura is a significant clinical skin manifestation for the prediction of skin tears in older individuals. Clinical assessment of purpuric skin lesions can easily be conducted at the bedside to permit early identification of individuals at risk of skin tears.

7.3. Chapter Summary.

This chapter discusses the results of baseline variables and the risk of skin tears at 6-months. The study findings suggest that changes to the structural and mechanical properties of skin arise from a multitude of factors including: chronological ageing, photoageing, difference in skin types, environmental exposure and lifestyle-related behaviours. The variation in the type of clinical manifestations reported in the literature and the ability to predict the risk of skin tears may relate to different geographical locations and the degree and extent to which the study samples are influenced by these factors.

The clinical manifestations of elastosis and purpura identified in this study infer an ageing population whose skin has largely been subjected to the influences of aged-related, photoaged-related, and lifestyle-related

factors that have impacted on the structural and mechanical properties of their skin. These factors suggest that aged-related and photoaged-related skin changes contribute to the cutaneous manifestations of elastosis and purpura, which multivariable logistic regression identified to be associated with skin tears. These findings suggest that either or both of these clinical skin manifestations in participants is connoted by an increased risk of skin tears. Accordingly, these clinical manifestations provide a simple but promising means for health care providers to predict the risk of skin tears in older individuals, which minimises the need to purchase expensive non-invasive technologies. Chapter 8 provides evidence of structural and mechanical property changes to ageing skin, and interprets these findings in relation to skin tears.

Chapter 8

Changes to the Structural and Mechanical Properties of Ageing Skin and Implications for Skin Tears

8.1. Introduction

As discussed in Chapter 7, this prospective cohort study identified two clinical manifestations (elastosis and purpura) that were significantly associated with the risk of skin tears in the participants. This finding has inordinate clinical significance for the assessment of ageing skin without the need to use expensive and sophisticated non-invasive equipment. Therefore, Chapter 8 presents expanded and specific discussion on the clinical relevance of elastosis and purpura in relation to ageing skin and the development of skin tears. Underlying these clinical manifestations were changes to structural skin proteins, which most likely have impacted on the mechanical stability and behaviour of ageing skin. This chapter draws together the literature on changes to the structural integrity and mechanical properties of ageing skin, and interprets these findings in relation to skin tears.

8.2. Clinical Manifestations Associated with Skin Tears

There is an apparent contradiction between the cutaneous manifestation of elastosis (with associated skin stiffness) and purpura (with loss of tissue structure and mechanical competency) and the risk of skin tears. These manifestations reflect the relative impact that intrinsic and extrinsic factors had on the skin properties of study participants.

Elastotic skin manifestations with its associated thickening and dysfunctional stiffening occurs on habitually exposed photoaged skin surfaces (Gundermann, Stark, & Boukamp, 2015; Paeon et al., 2013). In contrast, purpura with its atrophic changes can be attributed to either age-related or photoaged-related skin changes (Cox & Piette, 2010; Husain et al., 2011). Clinically, extrinsically aged skin manifests with hyperproliferation or

atrophic skin changes (Wiegand, Raschke, & Elsner, 2017). Initially, photoaged skin appears thickened and coarse with a dry rigid texture. In the later stages, atrophic changes from reduced ECM makes the skin appear thin with a soft and fragile texture (Ippolito et al., 2012; Riahi et al., 2016). Intrinsically aged skin only manifests in the atrophic form with a lax appearance (Wiegand et al., 2017).

The findings from this study suggest that there was substantial inter-individual variation in the clinical manifestations of participants skin from differences in ageing, photoageing, skin type, environmental exposure and lifestyle-related influences. These factors impacted on the structural integrity and mechanical stability of skin to increase the risk of skin tears in participants of this study.

The normal composite structure of skin and the architectural arrangement of the epidermis, DEJ, dermis and hypodermis permits skin to exhibit non-linear anisotropic behaviour that provides strength, flexibility and confers mechanical functionality to maintain the structural integrity (Lackner, Waldhauser, Major, Major, & Hartmann, 2013; Li, 2015). The anisotropic behavioural properties of skin provides it with the capability to stretch and contract in different directions, thereby permitting the body to move and respond to external forces without soft tissue tearing (Pawlaczyk, Lelonkiewicz, & Wieczorowski, 2013).

The following discussion focuses on the skin properties associated with the clinical manifestations of elastosis and purpura of the upper extremities relative to ageing and the structural integrity and mechanical stability of the epidermis, DEJ and dermis and the risk of skin tears. Examination of the hypodermis was beyond the scope of the present study and as the precise relationship of this structural component of skin with skin tears is unknown it will not be discussed further.

8.3. Epidermis

The findings from this study suggest that changes to the epidermis from photoaging and elastotic skin manifestations contributed to the risk of skin tears in participants. The structural integrity of the SC influences the biomechanical barrier properties and behaviour of skin, which is adversely altered with ageing (Biniek et al., 2015). The structural integrity and mechanical properties of the epidermis were indirectly examined in this study through measurements of TEWL and superficial skin hydration. In this study participants with cutaneous manifestations of elastosis had significantly higher TEWL and significantly lower skin hydration, which generally suggests disruption to the skin barrier. Previous research has shown that disruption of the skin barrier impairs the skin's mechanical properties and integrity (Darlenski, Sassning, Tsankov, & Fluhr, 2009; Pedersen & Jemec, 2006). Approximately 95% of the SC is composed of keratinocytes, which contain keratin and require sufficient hydration to govern normal epithelial stiffness and resilience (McKittrick et al., 2012; Moll, Divo, & Langbein, 2008). The level of skin hydration influences the extensibility and VE behaviour of corneocytes and the concomitant mechanical integrity of the epidermis (Bhushan & Tang, 2010). Disruption to the skin barrier diminishes the ability of epidermal cells to retain water and predisposes skin to injury (Liu & German, 2015). The lower the SC water content the greater and more constant are the applied mechanical forces (Vyumvuhore et al., 2015).

The skin texture of participants in this study showed considerable inter-individual variation, which was presumably influenced by both intrinsic ageing and the extent to which skin was subjected to environmental, recreational and lifestyle-related factors. Factors found to disrupt the permeability of the skin barrier included exposure to UV radiation and smoking. Both of these factors have been shown to impact on the skin barrier by reducing skin hydration and increasing the level of TEWL (Proksch, 2005). Environmental and lifestyle-related factors influence cellular cohesion and the structural and mechanical integrity of the skin by altering intercellular lipid content, reducing the level of skin hydration, and impairing the hydrolytic enzymes that are

needed to degrade the corneodesmosomes (Biniek et al., 2012; Ishida-Yamamoto & Igawa, 2015). Decreased degradation of the corneodesmosomes (intercellular adhesive structures) causes epithelial scales to accumulate on the skin that results in a rough, dull and flaky appearance that was frequently observed in participants (Del Rosso & Levin, 2011). Despite the lack of a clear trend in the sebum levels reported in the pilot study, the decline in the production of this complex mixture of lipids, which manifests as dry scaly skin may also have contributed to the functional decline and loss of skin integrity (Pochi, Strauss, & Downing, 1979).

8.4. Dermal-epidermal Junction

The DEJ was indirectly examined in the present study by measuring the transepidermal secreted proteins of type IV collagen. As previously reported, type IV collagen is a ubiquitous basement membrane component found in a range of tissue types including skin and blood vessels (Candiello et al., 2010). Significantly higher levels of type IV collagen were identified in the present study to be associated with increased risk of elastotic skin manifestations across the dorsal forearms of participants. The higher collagen type IV level suggests that age-related and photoaged-related skin changes impacted on the comparative elasticity, contraction and extensibility functional properties of the basement membrane and decreased the capacity of the DEJ tissue to resist mechanical stresses (Gkogkolou & Böhm, 2012, 2015; Halfter et al., 2015; Nowotny & Grune, 2014; Paegeon et al., 2015; Sell & Monnier, 2010).

Diminution of the rete pegs and ridges with concomitant loss of structural anchoring of the epidermis to the dermis is frequently cited in the literature as physiological factors, which increase the risk of skin to trauma related injuries such as skin tears (Bank & Nix, 2006; Bateman, 2012; Fleck, 2007; LeBlanc & Baranoski, 2014; McGough-Csarny & Kopac, 1998). The Pearson's product-moment coefficient identified a positive correlation in the present study between VE and type IV collagen, which suggested that the skin of the dorsal forearm of participants with clinical elastosis displayed a degree of

stiffness (Table 6.12). Dermal fibroblasts significantly stiffen with age to alter the VE behaviour of collagen fibres and lower the shear modulus to deformation (Schulze et al., 2010). The VE behaviour of skin normally protects it from external forces and injury by acting as a shock absorber to transmit mechanical tension, as well as providing flexibility when stress or shearing forces are applied (Everett & Sommers, 2012; Nemoto et al., 2012; Ruvolo Jr et al., 2007). Increased skin stiffness from aged-related and photoaged-related changes can contribute to friction and shearing-related injuries, which includes skin tears (Escoffier et al., 1989; Kottner, Lichterfeld, & Blume-Peytavi, 2013).

Conversely, participants with purpura of the upper and lower extremities were found to have statistically significantly lower levels of type IV collagen. The lower levels of collagen type IV associated with purpura suggests a decline in the structural integrity of the basement membrane of dermal blood vessels, which predisposed the skin of participants to ecchymotic lesions.

The findings of the present study suggest that micro-level changes to type IV collagen are implicated in the clinical manifestations of both elastosis and purpura. The small but statistically significant increased level of type IV collagen suggests that in this study the basement membrane of participants with elastic skin manifestations of the dorsal forearms had a degree of thickness, stiffness, loss of flexibility, and decreased extensibility which increased the risk of the fine mesh-like sheath to tear. Conversely, the lower level of type IV collagen associated with purpura suggests a decline in vascular integrity. Ageing, photoageing and lifestyle-related behaviours are implicated in the present study in structural changes to the DEJ to increase the risk of skin tears.

8.5. Dermis

The structural and mechanical properties of skin are primarily governed by collagen and elastic fibres, which are functional proteins located in the ECM of the dermis (Moronkeji & Akhtar, 2015). In this study, collagen and elastic fibre components were indirectly evaluated to identify any association

with skin tears. A 20-MHz B-mode high frequency ultrasound examined collagen levels by measuring whole skin thickness, whereas a negative suction chamber method evaluated elasticity. The findings from this study in relation to dermal collagen and elastic fibres and their influence on the mechanical behaviour of skin (and hence the risk of skin tears) is discussed in greater detail in section 8.5.1 and section 8.5.2.

8.5.1. Collagen fibres.

Skin thickness did not significantly differ in participants with and without elastotic skin manifestations. Skin thickness did however, significantly ($p < .001$) decrease in those participants with purpura. The dermal layer of skin principally consists of type I and type III fibril-forming collagen fibres (Ricard-Blum, 2010). While it was beyond the scope of the present study to specifically evaluate these skin collagens, they were indirectly examined using ultrasound technology to evaluate whole skin thickness.

Type I and type III collagens respectively account for about 80% and 15% respectively of skin collagen, and are integral to the maintenance of structural integrity (Li, 2015; Ploetz, Zycband, & Birk, 1991). The fibril-forming collagens of skin commonly assemble into well orientated super structures that confer tensile strength, load bearing capabilities and mechanical support properties (Gelse, Pöschl, & Aigner, 2003). Ageing reduces functionality and productivity of dermal fibroblasts, decreases the level of dermal collagen and causes fragmentation of structural skin proteins, which alter the mechanical behaviour of skin (Bailey, 2001; Egbert et al., 2014).

Yang et al. (2015) recently demonstrated that the mechanical properties of skin and the ability to resist deformation and tearing is attributed to the micro-level behaviour of collagen fibres. The ability of skin collagen to resist deformation is linked to four mechanisms including: straightening of fibrils, reorientation of fibrils towards the tensile (longitudinal) direction, elastic stretching and interfibrillar sliding (Yang et al., 2015). The micro-level structure of wavy skin collagen fibres is designed to increase resistance to tearing through reorganisation and alignment of fibrils towards the tensile

direction, which permits tissue to rotate, straighten, stretch and slide before tearing (Yang et al., 2015). The structural design of wavy collagen permits tissue to respond to multidirectional forces without disrupting the integrity of the skin (Dawber & Shuster, 1971; Ottani, Raspanti, & Ruggeri, 2001). Micro-level changes to the functional structure of collagen and elastic fibres are likely to modify the structural and mechanical properties of skin proteins and limit its anisotropic behaviour.

Like collagen type IV, type I collagen has reported to be susceptible to the cytotoxic accumulation of AGEs that contribute to the cross-linking of fibres (Fuller, 2016; Sharma, Kaur, Thind, Singh, & Raina, 2015; Wondrak et al., 2002). While cross-linking of collagen fibres is necessary for supporting fibrils and for providing skin with elasticity and mechanical stability, excessive cross-linking and associated stiffening of fibres from age, environmental and lifestyle-related factors can reduce tissue resilience and compromise the skin's biomechanical integrity (Panwar et al., 2015; Phillip, Aifuwa, Walston, & Wirtz, 2015).

As yet unexplored in relation to skin tears, it is conceivable that age-related changes to these collagens are implicated in these injuries. Research indicates that collagen fibres have a long lifespan, which are predisposed to ageing and the cumulative effects of skin photoageing from the accumulation of AGEs (Pageon et al., 2013; Verzijl et al., 2000). The AGEs progressively and irreversibly modify proteins, lipids and the extracellular matrix (Larsson et al., 2016; Verzijl et al., 2000). These processes degrade dermal architecture and cause loss of functional elastin, altered biomechanical behaviour and lead to elastotic manifestations, which are clinically confined to exposed skin surfaces (Castanet & Ortonne, 1997; Griffiths, 1992; Han et al., 2014).

Research of non-exposed tissue demonstrates glycation of skin collagen is age-related and increases by 33% between the ages of 20 and 80 years (Dunn, McCance, Thorpe, Lyons, & Baynes, 1991). Recent research of non-diabetic forearm skin showed AGEs accumulate across both non-exposed and exposed skin sites with higher quantities forming across photo-exposed

skin surfaces (Beisswenger et al., 2012; Pagoon et al., 2013). It has been postulated that biological ageing acts as a photosensitiser for the deposition of additional AGEs products from exposure to UV radiation (Beisswenger et al., 2012; Pagoon et al., 2013).

Ageing decreases fibroblast synthesis of collagen, which contributes to a decline in intact collagen fibres and loss of mechanical stimulation (Varani et al., 2006). Fragmentation of collagen fibres reduces mechanical signalling and impairs ECM fibroblast attachment that leads to thinning of the dermis and weakening of the skin's structural integrity (Fisher et al., 2008; Qin, Voorhees, Fisher, & Quan, 2014; Tu & Quan, 2016). Stretching or tension on the fibroblasts is crucial for normal production and degradation of collagen fibres (Fisher et al., 2008). Fragmented collagen, decreased total collagen, and the decline in cell-collagen fibres interaction characterises both chronological and photoaged skin (Lavker, 2002; Lavker, 1979; Smith Jr et al., 1962; Tu & Quan, 2016). While collagen synthesis progressively declines with age, the decreased production of new collagen is more evident across exposed skin surfaces (Varani et al., 2006). The decreased production of collagen may in part explain why some participants were more susceptible to skin tears than others.

8.5.2. Elastic fibres.

Study participants with cutaneous manifestations of elastosis had significantly ($p < .015$) reduced distensibility compared to participants without elastosis, which suggests increased tissue rigidity that limits the anisotropic behavioural properties of skin. Conversely, participants with purpura had significantly ($p < .005$) increased distensibility compared to participants without purpura, which suggests a loss of elasticity.

The structure of dermal elastic fibres consists of external fibrillin microfibrils and a central cross-linked elastin core that forms a composite structure with distinct behaviours (Sherratt, 2009). The elastin core accrues energy and influences passive recoil whereas the fibrillin microfibrils control elastogenesis (formation of elastic fibres), mediate cell signalling to govern

cellular activities, maintain tissue homeostasis, and reinforce the elastic fibre (Rappolee, 2003; Sherratt, 2009). Elastin is a functional ECM protein that provides the dermis with extensibility, recoil and resilience properties (Sandberg, Soskel, & Leslie, 1981). Elastin has the capacity to extend over 100% without being damaged (Humphrey, 2008). The half-life of elastin is reported to be about 70 years, which provides this protein with stability and enables it to retain its mechanical functional properties over time (Keeley, Bellingham, & Woodhouse, 2002; Shapiro et al., 1991). Recently, researchers isolated elastin from skin biopsies from both chronological and photoaged skin samples and established that after the age of 70 years elastin undergoes severe structural modifications (Mora Huertas, Schmelzer, Hoehenwarter, Heyroth, & Heinz, 2016).

While ageing is associated with the degradation of elastin fibres, these effects are more pronounced across photo-exposed skin surfaces than non-exposed skin surfaces (Mora Huertas et al., 2016). The findings from the present study demonstrated that the mean distensibility and retraction times were delayed across the dorsal forearm of those participants with clinical elastosis compared to participants without clinical elastosis (Table 6.9). Thus, in participants with clinical elastosis of the dorsal forearm, the skin was rigid from dysfunctional stiffening of the ECM resulting from changes to the structural and mechanical integrity of elastic fibres to limit the anisotropic behaviour of skin and increase the risk of skin tears.

Conversely, participants with clinical signs of purpura demonstrated significantly decreased mean skin thickness and distensibility time compared to participants without purpura (Table 6.14). These changes suggest a loss of supporting structures and reduced tissue stiffness that may contribute to increased tissue deformation (Table 6.17). Increased tissue displacement from loss of skin elasticity intensifies the effects of skin hysteresis (deformation), wrinkling, tissue displacement, rolling, and shearing during frictional interaction in aged skin (Derler & Gerhardt, 2012; Gerhardt et al., 2009). The loss of supporting tissue and increased distensibility suggests

that the structural and mechanical properties of participants' skin were reduced, which predisposed it to the influences of shearing forces and tissue displacement, which increased the risk of skin tears.

8.6. Dermatoporosis.

The researcher believes that participants who sustained multiple skin tears over the 6-month period had more extensive atrophic skin changes than participants who sustained only one or two skin tears. Exactly 50% (n = 112) of all skin tears occurred in just 16.8% (n = 12) of participants. This finding suggests that in those participants there was excessive loss of structural supporting skin proteins and mechanical stability, which connoted with stages 1–3 of the dermatoporosis syndrome (Kaya & Saurat, 2007). Changes to the structural properties of skin increases skin fragility and the risk of skin tears from any physical force.

8.7. Chapter Summary

A combination of chronological, environmental and lifestyle-related factors contributed to age related skin changes observed in this study, and are proposed to have impacted on the structural integrity, mechanical behaviour and resistance of ageing skin. These changes contributed to an elevated risk of skin tears in this sample of Australian aged care residents. This finding challenges the current clinical definition of skin tears and provides the evidence to better define these age-related wounds. Chapter 9 summarises the research findings, strengths and limitations and the implications for clinical practice.

Chapter 9

Conclusions and Recommendations

9.1. Introduction

This chapter summarises the findings of the research in relation to the study participants, achievement of the two objectives, the strengths and limitations, and the implications for clinical practice.

In total, 41% of the aged care residents who participated in this study sustained a skin tear, with ageing indirectly associated with the risk of these wound types. Age was identified in the statistical models as a risk factor for cutaneous manifestations of elastosis (Table 6.11) and purpura (Table 6.16), which in turn were directly associated with the increased risk of skin tears (Table 6.7). The significance of age as a risk factor for skin tears is consistent with prior research by Newall et al. (2016). The identification of age as a risk factor for skin tears is logical in the context of progressive temporal changes to the structural supporting proteins of skin as individuals age.

In this study 58% of skin tears occurred on the upper extremities and 34% occurred on the lower extremities of the aged care participants (Table 6.2). These levels are consistent with a large body of existing research into aged care populations, which has demonstrated the upper extremities have higher incidents of skin tears compared to the lower extremities (Koyano et al., 2014; LeBlanc et al., 2013; Malone et al., 1991; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; Sanada et al., 2015; White et al., 1994). The upper extremities are also associated with the greatest amount of exposure to UV radiation and photoaged related skin changes (Battie & Verschoore, 2012; D'Orazio, Jarrett, Amaro-Ortiz, & Scott, 2013).

This study also identified a history of skin tears to be significantly ($p = .002$) associated with increased risk of skin tears. This result is consistent with previous studies (LeBlanc et al., 2013; McGough-Csarny & Kopac, 1998; Payne & Martin, 1990; Sanada et al., 2015). Over the 6-month study period, the 50% of skin tears that occurred in just 16.8% of participants suggests

these residents may have severe loss of structural supporting skin proteins and mechanical stability, which connotes with stages 1–3 of the dermatoporosis syndrome (Kaya & Saurat, 2007). Changes to structural proteins and the mechanical stability properties of skin on the upper extremities from intrinsic and extrinsic factors are likely explanations for the increased risk of skin tears in aged care participants in this study. The relative extent of such changes is likely to vary between individuals and across skin sites, which may explain why some participants sustained skin tears more frequently than other individuals.

9.2. Objective 1 — To examine the feasibility and reliability of non-invasive technologies to objectively quantify morphological and physiological properties of ageing skin.

A variety of non-invasive technologies were demonstrated to objectively and reliably measure a substantial range of properties in ageing skin. The instruments selected (DermaLab Combo®, Skin-pH-Meter®) for this study recorded good intra-rater reliability for most skin properties over a single event measurement (three consecutive measurements). Some of the variables however, were not as reliable and these included erythema, CIE L, CIE a, CIE b, and sebum at a single measurement event and over time. The ICC between events (measurements at baseline and again at 6-months) suggested some measurement values (SLEB, skin thickness) were highly correlated, whereas the other variables (TEWL, hydration, skin surface pH) had greater variability. The ICC value for each skin property decreased between 4-weeks and 6-months. The variability in results may have arisen from a range of factors including variation in measurement technique and natural physiological changes in skin properties. Nevertheless, the findings of this study demonstrated the DermaLab Combo® and pH-Meter® were non-invasive devices that can provide objective, quantifiable, reliable and precise measurements of ageing skin properties.

9.3. Objective 2 — To develop a multivariable prediction model using baseline individual characteristics, skin characteristics and morphological and physiological skin properties to predict incidents of skin tears at 6-months, in a sample of aged persons.

Multivariable logistic regression modelling identified five variables that significantly predicted the risk of developing a skin tear over the 6-months study period. Male gender, two adverse events (previous history of skin tears and a history of falls), and two clinical manifestations (cutaneous elastosis and purpura) significantly predicted the risk of skin tears.

The analysis did not identify any morphological or physiological skin property that significantly predicted the risk of skin tears at 6-months. Additional multivariable analysis however, showed some skin properties significantly predicted the risk of clinical manifestations of elastosis and purpura. Accordingly, three individual variables (age, gender, smoking), three clinical skin variables (uneven skin pigmentation, cutis rhomboidalis nuchae, history of AK) and one skin property variable (collagen type IV) predicted the risk of cutaneous manifestations of elastosis. In contrast, four individual characteristics (age, history of skin tears, history of falls, antiplatelet therapy) and three skin properties (pH, SLEB of the forearms, skin thickness) predicted the risk of purpura.

Analysis using sensitivity and specificity, together with a receiver operator characteristic (ROC) curve, indicated the proposed skin tear model provided very good discrimination for correctly classifying participants with and without skin tears.

9.4. Study strengths

The strengths of this study are discussed in relation to the two objectives.

9.4.1. Objective 1.

A major strength of this prospective study is the research design, methodology and statistical methods that were used to identify factors that predicted the risk of skin tears. The study assessed and measured a broad

range of variables in highly-controlled measurement environments to generate a reliable and high-quality dataset. The collection of data by a single investigator maintained the consistency of data collection, enabled data to be gathered sequentially, and examined multiple variables. Data validation and quality control measures ensured the integrity and completeness of the data with a single investigator, which avoided the complexities of inter-rater reliability. Strict follow-up resulted in 86.5% of participants being reassessed 6-months after their initial assessment. A high-quality prospective study is specified by Alshryda and Wright (2014) as having greater than 80% of individuals (who were enrolled into a study at the same time point) followed-up.

The study protocol and the technologies that were used in this study enabled the identification of underlying morphological and physiological skin changes, which in turn provided a clearer understanding of the mechanical behaviour of ageing skin and the risk of skin tears.

9.4.2. Objective 2.

A major strength of this study is that it is the first prospective study in Australia to follow a cohort of aged care residents for a period of 6-months to assess the predictive ability of a comprehensive list of baseline variables and relate them to the risk of skin tears. Two previous cohort studies conducted in Japan over a 3-month and 8-month period examined a smaller number of variables (Koyano et al., 2017; Sanada et al., 2015).

The present study provides more robust evidence of risk factors for the prediction of skin tears in older individuals than any previous study. The level of evidence for this prospective cohort study is consistent with level III-2 of the National Health and Medical Research Council and level 3 of the Oxford Centre for Evidence-Based Medicine evidence hierarchy (Australian Government National Health and Medical Research Council, 2009; Oxford Centre for Evidence-Based Medicine Working Group, 2011). This study ranks higher in the evidence hierarchy than previous skin tear prevalence studies, which have a level IV evidence grade.

This study also enhances our understanding of the biology of ageing skin because it was conducted *in vivo*, which permitted the temporal examination of individual characteristics, skin characteristics, and morphological and physiological skin properties. An important strength of this study is the analytical process undertaken to evaluate these variables. The analysis led to the development of a predictive model that provides health care workers with a distinct set of variables with which to evaluate older individuals at risk of skin tears. The predictive model identified five baseline variables (male gender, history of skin tears in the previous 12-months, history of falls within the preceding 3-months, cutaneous manifestations of elastosis and purpura) that were significant independent predictors of skin tears at 6-months. The advantage of this predictive model is its simplicity and relevance to any health care setting. It dispenses with the need to purchase expensive equipment that requires specialised training, is time consuming to use, involves regular calibration and maintenance, and may be intimidating for both residents and staff.

The findings from this study have clear practical and clinical implications for both residents and health care providers in Australia. The five skin tears predictors will help guide decision-making as they can readily be assessed and evaluated within the privacy of an individual's room and with relative ease by all health care providers, regardless of their level of training or experience. The predictive model has the potential to support evidence-based decision making by more accurately identifying elderly Australians at risk of skin tears, permitting effective preventive management through early intervention and allocation of resources, which concomitantly reduces healthcare costs. However, it is recommended that replicated studies of similar methodological rigour amongst other elderly populations be undertaken to confirm this finding.

To date, this is the most comprehensive study to have evaluated a broad range of variables for predicting the risk of skin tears in an aged care resident population. It is also the first Australian study to have used non-invasive

technologies to objectively quantify ageing skin properties and identify variables that predict the risk of skin tears. The results of this study are therefore highly relevant to older Australians in residential aged care facilities.

This study also provides a foundation for improving the assessment, identification and classification of skin manifestations in older individuals, through standardisation of terminologies. This is the first study to have examined skin texture and recognised the significance of cutaneous manifestations of elastosis as a predictor of skin tears. A more effective approach to assessing skin manifestations is needed to better identify individuals at risk of skin tears, improve clinical documentation and reporting, and enable comparison of research results across different populations.

Finally, this study provides a valuable basis for conducting future evidence based research into skin tears across different sample groups, health settings and geographical locations and will inform a systematic review.

9.5. Study limitations

Several limitations were identified which are discussed in relation to the key objectives.

9.5.1. Objective 1.

A limitation of this study was that it was conducted in a non-clinical environment (the participant's own room), which posed a distinct set of challenges in terms of individual (acclimatisation) and environmental (temperature, humidity, air turbulence, lighting) conditions for measuring skin properties. The development and adherence to a study protocol helped mitigate the impact of these conditions and ensured measurement of skin properties were consistently and reliably recorded. Nonetheless, the controlled conditions required for optimal use of the instruments for measuring ageing skin properties may be hard to replicate within the daily routine of residents and aged care facilities.

9.5.2. Objective 2.

A potential limitation for extrapolating the results of this study to the broader population of aged care residents was the inability to randomly select the residential care facilities and recruit the residents to participate in this study. The participating facilities were from a single service provider and recruitment of residents was based on their informed consent and willingness to participate, which may have resulted in some bias in the selection process. Volunteer bias has previously been shown to arise where those who volunteer (based on their perceived interest in the study) may not necessarily be representative of the general population.

The 6-month time period and the relative uniformity of the study sample in terms of individual characteristics, skin characteristics, and morphological and physiological skin properties and the impact of chronological, environmental and lifestyle-related factors could potentially have impacted on the results and limit the generalisation of the findings. Nevertheless, these findings provide greater insight into the prevalence and predisposing factors for skin tears within Australia and the influence of intrinsic and extrinsic factors on the ageing of skin.

Grouping of skin tears across all sites, to increase the statistical power of the analysis, is a potential limitation of this study. A much larger sample population would have increased the statistical power to detect skin tears by specific site.

A further limitation of this study was the lack of an objective quantification basis to measure the degree of clinical elastosis (firmness or coarseness) across exposed skin surfaces. The ability to objectively quantify elastosis is important for the accurate identification of older individuals at risk of skin tears.

9.6. Recommendations for Clinical Practice and Future Research

The following recommendations have emerged from this study, and seek to improve clinical practice and enhance knowledge of skin tears and their

prevention. The recommendations will also guide future research. This study has made a significant contribution to improving the empirical understanding of factors associated with the risk of skin tears. The early identification of older individuals at risk of skin tears has potential benefits through directing timely and targeted preventive strategies, optimising QoL, more effective utilisation of resources and hence reduced health care expenditure. The findings also have implications for skin assessment practices and care planning across a broad range of health sectors including residential care facilities, community settings, hospitals and general medical practices.

9.6.1. Validation of risk factors.

Validation of the five skin tear risk factors that were identified in this study is recommended to determine the reliability and validity amongst other ageing populations and across different health care sectors.

9.6.2. Revision of skin tear definition.

It is recommended that the results of this study inform a more explicit skin tear definition. Consideration should be given to amending the definition of a 'skin tear' to explicitly recognise the influences that aged related structural changes have on the risk of skin tears. A proposed definition is 'A skin tear is a superficial or full thickness injury that results from friction or shear forces, which principally occurs on the extremities of older individuals with clinical signs of elastosis and/or purpura from changes to the structural and mechanical supporting properties of skin'.

At present, the most commonly cited definition of a skin tear in the literature was coined by Payne and Martin in 1993. This definition describes a cause (friction and shear), effect (partial or full thickness wound), population group (older adults) and site (principally on the extremities) of injury. This operational definition was based on the authors' understanding, at that time, of the biological mechanisms associated with aged-related skin changes. More recently, a review of this definition by the International Skin Tear Consensus Panel simplified the wording of Payne and Martin (1993)

and dispensed with “principally on the extremities of older adults” and added the term “blunt” to the wording (LeBlanc & Baranoski, 2011). The scope of the definition narrowed to emphasise a cause (shear, friction or blunt force) and effect (partial or full-thickness) relationship that could easily be confused with ‘lacerations’, a wound that is defined by the National Library of MeSH as “torn, ragged, mangled wounds” (National Library of Medicine, 2016).

Based on the findings of this study a revised definition of a skin tear needs to be applied, which takes into consideration the scope and underlying influence that structural proteins and mechanical properties changes have on ageing skin.

9.6.3. Development of a skin tear risk assessment tool.

It is recommended that a generic evidence-based skin tear risk assessment tool (RAT), which incorporates validated findings be developed. The RAT would guide clinical decision making by providing a consistent, systematic and evidence-based framework for identifying aged care residents at risk of skin tears. It would also help standardise terminology and improve reporting and would direct: tailored and timely education for all health care workers in the identification of clinical characteristics; tailored and timely education of residents concerning the importance of preserving skin integrity; establishing a regimen for conducting full body skin assessment; establishing an electronic data management system that records both skin manifestations and skin tears.

The skin tear risk assessment could form part of the routine clinical care provided to older individuals. Based on the extent of clinical indicators, the skin tear risk assessment tool could form the basis for guiding preventative measures such as the application of moisturisers and skin protective sleeves. The early identification of skin tear risk factors and targeted preventive strategies is likely to generate significant savings for health care providers.

9.6.4. Further testing of the non-invasive technologies.

It is recommended that the two non-invasive devices (DermaLab Combo®, pH-Meter®) be further applied with the same robust research methodology, to examine other wounds that disproportionately occur in older individuals, such as leg ulcers and pressure-related injuries.

9.6.5. Additional skin property research.

In conclusion, this study has made a significant contribution to improving the empirical understanding of skin tear risk factors. The early identification of older individuals at risk of skin tears has significant potential benefits through greater awareness of age-related skin changes, directing timely and targeted preventive strategies, optimising QoL, more effective utilisation of resources and hence reduced health care expenditure across a broad range of health sectors.

While the findings from the present study are of particular interest for identifying aged Australian residents at risk of skin tears, the implications for other ageing populations are significant. This study provides a valuable source of material to stimulate and inform future research that will ultimately lead to a greater awareness of skin tears and a better understanding of ageing skin properties. It is recommended that future research focus on: objectively quantifying elastosis in elderly resident's skin and its correlation to skin tear incidents; understanding the interactive effects of ageing skin properties; and examine the influence that epidermal and adipose tissue have on the development of skin tears.

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Order date	Apr 21, 2017
Licensed Content Publisher	MA Healthcare Limited
Licensed Content Publication	Journal of Wound Care
Licensed Content Title	A review of patient and skin characteristics associated with skin tears
Licensed Content Author	R. Rayner, K. Carville, G. Leslie, et al
Licensed Content Date	Sep 2, 2015
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The standard identifier	0969-0700
Expected completion date	Jul 2017
Expected size (number of pages)	250
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Appendix B

Consent for Reproduction of Wound Images



MEMORANDUM

To Ms Robyn Rayner RN, PhD Candidate

From Keryln Carville RN PhD
Professor Primary Health Care & Community Nursng

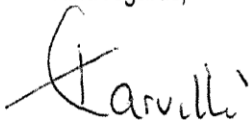
Date 6 September, 2017

Subject **CONSENT FOR REPRODUCTION OF WOUND IMAGES**

Dear Robyn,

On behalf of Silver Chain I give permission for you to reproduce the images of skin conditions and skin tears obtained from Silver Chain clients and photographed by you with their consent as per your Figure 2.2, Figure 2.3, Figure 2.4, and Figure 2 in your PhD thesis. Consent is given to use the images with all due respect to confidentiality and no identification of individuals.

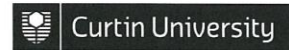
Kind regards,



Keryln Carville

Appendix C

Curtin University Ethics Approval Form



Memorandum

To	Professor Keryln Carville, Nursing and Midwifery
From	Professor Stephan Millett, Chair Human Research Ethics Committee
Subject	Protocol Approval RD-23-13
Date	26 June 2013
Copy	Robyn Rayner, Nursing and Midwifery Professor Gavin Leslie, Nursing and Midwifery Dr Pamela Roberts, Nursing and Midwifery

Office of Research and Development
Human Research Ethics Committee

TELEPHONE 9266 2784

FACSIMILE 9266 3793

EMAIL hrec@curtin.edu.au

Thank you for your "Form C Application for Approval of Research with Low Risk (Ethical Requirements)" for the project titled *"Identification of skin characteristics associated with skin tears on older adults"*. On behalf of the Human Research Ethics Committee I am authorised to inform you that the project is approved.

Approval of this project is for a period of twelve months **25-06-13 to 24-06-14**.

The approval number for your project is **RD-23-13**. Please quote this number in any future correspondence.

Your approval has the following conditions:

- i) Annual progress reports on the project must be submitted to the Ethics Office.
- ii) **It is your responsibility, as the researcher, to meet the conditions outlined above and to retain the necessary records demonstrating that these have been completed.**

Applicants should note the following:

It is the policy of the HREC to conduct random audits on a percentage of approved projects. These audits may be conducted at any time after the project starts. In cases where the HREC considers that there may be a risk of adverse events, or where participants may be especially vulnerable, the HREC may request the chief investigator to provide an outcomes report, including information on follow-up of participants.

Our website https://research.curtin.edu.au/guides/ethics/low_risk.cfm contains all relevant forms including:

- Completion Report (to be completed when a project has ceased)
- Amendment Request (to be completed at any time changes/amendments occur)
- Adverse Event Notification Form (if a serious or unexpected adverse event occurs)

Yours sincerely



Professor Stephan Millett
Chair, Human Research Ethics Committee

Please Note: The following standard statement must be included in the information sheet to participants:

This study has been approved under Curtin University's process for low-risk Studies (Approval Number RD-23-13). This process complies with the National Statement on Ethical Conduct in Human Research (paragraph 5.1.7 and paragraphs 5.1.18-5.1.21). For further information on this study contact the researchers named above or the Curtin University Human Research Ethics Committee. c/- Office of Research and Development, Curtin University, GPO Box U1987, Perth 6845 or by telephoning 9266 9223 or by emailing hrec@curtin.edu.au.

Appendix D

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Format	electronic
Portion	figures/tables/illustrations
Number of figures/tables/illustrations	1
Figures	Figure 1. CIELAB color space
Author of this NPG article	no
Your reference number	None
Title of the article	Measurement of morphological and physiological skin properties in aged care residents: A test-retest study
Publication the new article is in	International Wound Journal
Publisher of your article	John Wiley & Sons Ltd
Author of the article	Robyn Rayner, Keryn Carville, Gavin Leslie
Expected publication date	Jan 2016
Estimated size of new article (number of pages)	10
Total	0.00 AUD
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Appendix E

Literature Guiding the Assessment of Skin Properties

Guidance documents

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Appendix F

Study Protocol

Study protocol	Rationale
<p>Study population</p> <p>Inclusion</p> <ul style="list-style-type: none"> • Consenting aged care residents • Aged 65 years and over <p>Exclusion</p> <ul style="list-style-type: none"> • Residents who decline to participate, in pain or who have a terminal illness • Presence of a connective tissue disorder <ul style="list-style-type: none"> ○ Systemic sclerosis ○ Localised scleroderma ○ systemic lupus erythematosus ○ Keloid scarring ○ Hypertrophic scarring ○ Eosinophilic fasciitis ○ Lichen scleroseus ○ Graft-versus-host disease ○ Ehlers-Danlos syndrome ○ Cutis laxa ○ Bullous pemphigoid ○ Lymphoedema bilateral extremities 	<ul style="list-style-type: none"> • Alters skin thickness measurements
<p>Stabilisation and control of measuring conditions</p> <p>Environment</p> <ul style="list-style-type: none"> • Temperature - 20-22 ± 1°C • Humidity - 40-60% • Limit air turbulence • Avoid direct and close light sources <p>Resident</p> <ul style="list-style-type: none"> • Avoid application of moisture to for 24-hours prior to the assessment • Avoid washing for 12-hours prior to the assessment • Lie supine for 15-30 minutes • Measuring site remains exposed • Avoid caffeine consumption 30 minutes prior to assessment • Avoid smoking 30 minutes prior to assessment • Avoid application skin care products • Measure skin surface temperature at test site • Repeated measurements to be conducted at comparable time and study conditions <p>Instrument</p> <ul style="list-style-type: none"> • Calibrate instruments on a regular basis • Warm head of probe to skin surface temperature 	<ul style="list-style-type: none"> • Stabilises testing environment for optimum performance of measurement devices • Stabilises clinical testing • Increases accuracy and reproducible of measurements • Affects measurement results • Increases accuracy and reproducible of measurements • Ensures device measures accurately • Ensures results are accurate and reproducible

<ul style="list-style-type: none"> • Avoid touching the measuring probe • Handle device and probes with care • Probe to be applied perpendicular to skin surface • Same operator to perform measurements • Minimise amount of time that probe is applied to skin 	<ul style="list-style-type: none"> • Increases accuracy and reproducibility of measurements
<p>Measuring process</p> <ul style="list-style-type: none"> • Wash hands prior to, during and following assessment • Explain procedure to resident and reaffirm resident's consent • Draw curtains around resident's bed • Lie resident flat and make comfortable for 15-30 minutes <ul style="list-style-type: none"> ◦ Expose forearms, lower legs and left abdominal region • Complete data collection form after each measurement • Measure skin surface temperature • Complete biophysiological skin assessments in the following order <ul style="list-style-type: none"> ◦ Colour ◦ TEWL ◦ Hydration ◦ pH ◦ Ultrasound ◦ Elasticity ◦ Sebum • Three consecutive measurements to be taken 10 mm apart at designated test sites • Complete vascular assessment <ul style="list-style-type: none"> ◦ Toe brachial index ◦ Photoplethysmography • Reposition resident • Wash hands • Clean and store equipment • Finalise paper work 	<ul style="list-style-type: none"> • Reduce risk of cross infection • Confirms resident support • Maintains resident's privacy and dignity • Increases accuracy and reproducibility of measurements • Hard copy records completed • Increases accuracy and reproducibility of measurements • Measured skin properties in sequential order • Maintains accuracy, improves efficiency and client comfort • Distance minimises impacting on skin properties • Measured skin properties • Ensure resident is left comfortable • Reduce risk of cross infection • Finalises records and check for completeness

Appendix G

Data Collection Form

Date: ____/____/____ (dd/mm/yy)

Time: ____ (hours)

Residential care facility _____

Resident number: _____

Room temperature _____ Room humidity _____

PERSONAL DETAILS

1. Demographic details

Age: _____ (years) Date of birth _____

Sex: Male ☐ Female ☐

Ethnicity: _____

Weight: _____ Height: _____

BMI: _____

Previous occupation: _____

Allergies _____

2. Medical history

Heart disease ☐ Respiratory disease ☐

Diabetes Type I ☐ Diabetes Type II ☐

Hypothyroidism ☐ Hypoalbuminism ☐

COPD ☐ Peripheral arterial disease ☐

Uraemia ☐ Renal disease ☐

Paralysis ☐ Contractures ☐

CVA ☐ Malignancy ☐

Osteoporosis ☐ History of skin condition ☐

Other _____

3. Social history

Currently smoke? Yes ☐ No ☐

a. If answered yes for the above how often do you smoke?

Daily ☐ Weekly ☐ Occasionally ☐

b. How many do you smoked? _____

c. What age did you start smoking? _____

Past history of smoking Yes ☐ No ☐

a. If answered yes for the above how often did you smoke?

Daily ☐ Weekly ☐ Occasionally ☐

b. How many did you smoke? _____

c. What age did you start smoking? _____

d. What age did you stop smoking? _____

Currently drink alcohol? Yes ☐ No ☐

a. If answered yes for the above how often do you drink?

Daily ☐ Weekly ☐ Occasionally ☐

b. How much do you drink? _____

c. What age did you start drinking? _____

Past history of drinking alcohol Yes ☐ No ☐

a. If answered yes for the above how often did you drink?

Daily ☐ Weekly ☐ Occasionally ☐

b. How many did you drink? _____

c. What age did you start drinking? _____

d. What age did you stop drinking? _____

4. **Braden scale** (Braden & Bergstrom, 1988) score _____

5. **Medications**

Anti-inflammatories	<input type="checkbox"/>	Anticoagulants	<input type="checkbox"/>
Diuretics	<input type="checkbox"/>	Opioids	<input type="checkbox"/>
Antidepressants	<input type="checkbox"/>	Antiplatelets	<input type="checkbox"/>
Antihypertensives	<input type="checkbox"/>		
Hormone replacement therapy	<input type="checkbox"/>		
Corticosteroids	Systemic <input type="checkbox"/>	Topical <input type="checkbox"/>	Inhalation <input type="checkbox"/>
Other	_____		

SKIN CARE REGIMEN

6. **Type of cleansing product** Soap ☐ pH neutral cleanser ☐

7. Is a moisturiser applied to the:

Forearms? Yes ☐ No ☐
Legs? Yes ☐ No ☐

8. If yes, how regularly is a moisturiser applied to the forearm?

Daily ☐ Twice daily ☐ Ad hoc ☐

If yes, how regularly is a moisturiser applied to the legs?

Twice daily ☐ Daily ☐ Ad hoc ☐

SKIN CHARACTERISTICS

Clinical appearance of the skin

9. Fitzpatrick skin type _____

10. Skin appearance

Primary senile purpura <input type="checkbox"/>	Secondary senile purpura <input type="checkbox"/>
Ecchymosis <input type="checkbox"/>	Haematoma <input type="checkbox"/>
Oedema <input type="checkbox"/>	Pseudoscars <input type="checkbox"/>
Previous healed skin tears <input type="checkbox"/>	Other scarring <input type="checkbox"/>

11. Presence of skin condition

Eczema/dermatitis <input type="checkbox"/>	Psoriasis <input type="checkbox"/>
Actinic keratosis <input type="checkbox"/>	Other <input type="checkbox"/>

12. Presence of pitting oedema Yes ☐ No ☐

0 Nil
+ Slight indentation with normal anatomical contours
++ Deeper indentation which lasts longer + with fairly normal contours
+++ Deep indentation which remains after several seconds with obvious swelling
++++ Deep indentation that remains for minutes with frank swelling

	0	+	++	+++	++++
Right forearm					
Left forearm					
Right leg					
Left leg					
Abdomen					

13. Presence of skin hair

	Absent	Light	Moderate	Hairy
Right forearm	0	1 2 3	4 5 6	7 8 9
Left forearm	0	1 2 3	4 5 6	7 8 9
Right leg	0	1 2 3	4 5 6	7 8 9
Left leg	0	1 2 3	4 5 6	7 8 9
Abdomen	0	1 2 3	4 5 6	7 8 9

PRESENCE OF SKIN TEARS

14. Are skin tear present? Yes ☐ No ☐

15. Number of skin tears _____

16. Skin tear location and STAR Tool Classification

Location

Classification

Skin tear 1 _____ STAR Tool _____

Skin tear 2 _____ STAR Tool _____

Skin tear 3 _____ STAR Tool _____

Skin tear 4 _____ STAR Tool _____

Skin tear 5 _____ STAR Tool _____

DermaLab scan

17. Skin surface temperature

	1	2	3	Average
Right forearm				
Left forearm				
Right leg				
Left leg				
Abdomen				

18. Melanin abdomen

	1	2	3	Average
Melanin				

19. Trans-epidermal water loss

Right forearm

	g/m ² /hr	Upper °C	Lower °C	RH upper	RH lower	Environ °C	Environ RH
1							
2							
3							

Left forearm

	g/m ² /hr	Upper °C	Lower °C	RH upper	RH lower	Environ °C	Environ RH
1							
2							
3							

Right leg

	g/m ² /hr	Upper °C	Lower °C	RH upper	RH lower	Environ °C	Environ RH
1							
2							
3							

Left leg

	g/m ² /hr	Upper °C	Lower °C	RH upper	RH lower	Environ °C	Environ RH
1							
2							
3							

Abdomen

	g/m ² /hr	Upper °C	Lower °C	RH upper	RH lower	Environ °C	Environ RH
1							
2							
3							

20. Hydration

	1	2	3	Average
Right forearm				
Left forearm				
Right leg				
Left leg				
Abdomen				

21. pH

	1	2	3	Average
Right forearm				
Left forearm				
Right leg				
Left leg				
Abdomen				

22. Ultrasound
Right forearm

	SLEB (μm)	Skin thickness (μm)	Intensity (score)	Distance (μm)	Intensity
1					
2					
3					

Left forearm

	SLEB (μm)	Skin thickness (μm)	Intensity (score)	Distance (μm)	Intensity
1					
2					
3					

Right leg

	SLEB (μm)	Skin thickness (μm)	Intensity (score)	Distance (μm)	Intensity
1					
2					
3					

Left leg

	SLEB (um)	Skin thickness (um)	Intensity (score)	Distance (um)	Intensity
1					
2					
3					

Abdomen

	SLEB (um)	Skin thickness (um)	Intensity (score)	Distance (um)	Intensity
1					
2					
3					

23. Elasticity**Right forearm**

	VE (Mpa)	E (Mpa)	Retraction (ms)
1			
2			
3			

Left forearm

	VE (Mpa)	E (Mpa)	Retraction (ms)
1			
2			
3			

Right leg

	VE (Mpa)	E (Mpa)	Retraction (ms)
1			
2			
3			

Left leg

	VE (Mpa)	E (Mpa)	Retraction (ms)
1			
2			
3			

Abdomen

	VE (Mpa)	E (Mpa)	Retraction (ms)
1			
2			
3			

Limb perfusion**24. Toe brachial pressure index**

Right arm BP _____

Left arm BP _____

Right toe BP _____

Left toe BP _____

Right TBI _____

Left toe TBI _____

25. Photoplethysmography

Right leg RT _____

Left leg RT _____

Right leg ½ RT _____

Left leg ½ RT _____

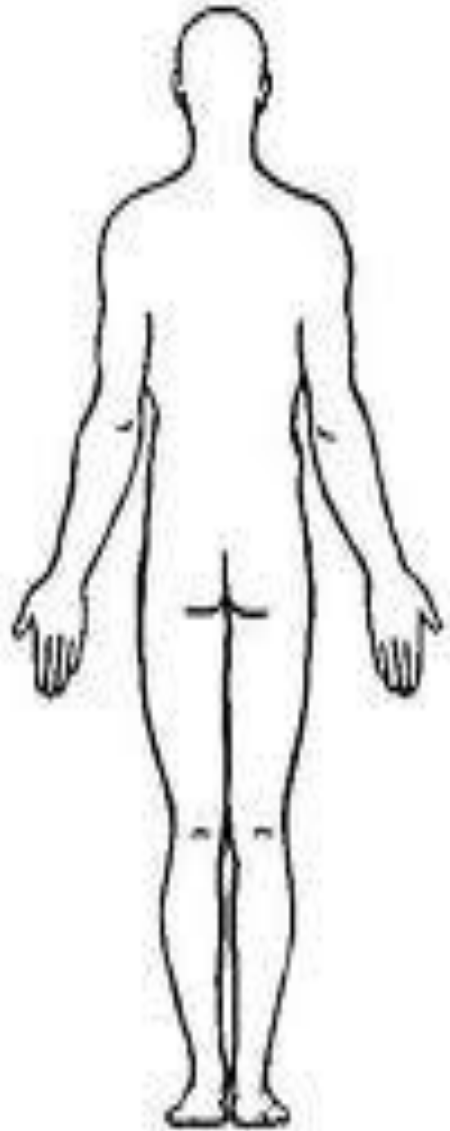
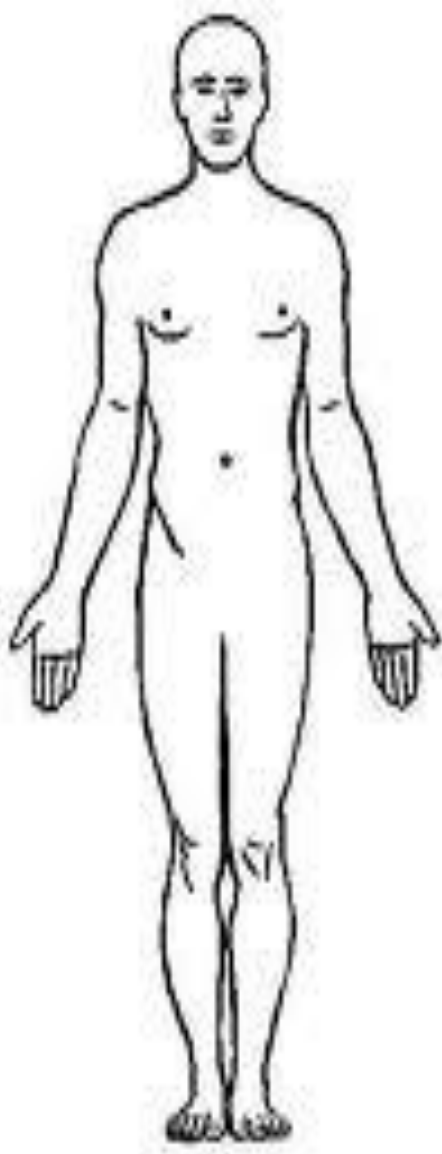
Appendix H

Skin Assessment Form

	Characteristic or manifestation	Location	Site	No	Yes
Intrinsic skin characteristics	Lax skin	Generalised			
	Fine wrinkles	Face			
Extrinsic skin characteristics	Coarse wrinkles	Face			
	Lentigines	Extremities			
	Purpura ≤ 20 mm	Extremities			
	Ecchymosis ≥ 20 mm	Extremities			
	Uneven pigmentation	Extremities			
	Yellowness	Generalised			
	Permanent redness	Extremities			
	Elastosis	Extremities			
	Pseudoscars	Extremities			
	History of actinic keratosis	Extremities			
	History of malignant skin lesions	Extremities			
	Cutis rhomboidalis nuchae	Neck			
Additional skin characteristics	Bruising	Extremities			
	Upper extremity oedema	Extremities			
	Lower extremity oedema	Extremities			
	Haematoma	Extremities			
	Healed skin tears	Extremities			
	Scar tissue	Extremities			

Appendix I

Location of Skin Characteristic



Key

Senile purpura – P

Pseudoscars – F

Elastosis – E

Skin tears – ST

Ecchymosis – B

Haematoma – H

Oedema – O

Other scarring – SC

Appendix J

Aged Care Facilities and Study Sample

Pilot study	Number of residents assessed
80 bed regional aged care facility	31
Total number of residents assessed	31

Major study	Number of residents assessed
80 bed regional aged care facility	51
160 bed regional aged care facility	90
90 bed metropolitan aged care facility	39
30 bed metropolitan aged care facility	20
Total number of residents assessed	200

Appendix K

Information Letter to the General Practitioner



Dear (insert GP name)
(Insert Date)

RE: Skin Tear Research Study

The Bethanie Group Inc. has approved a research study to identify skin characteristics associated with skin tears in older adults.

The aim of the research is to identify specific skin characteristics associated with skin tear occurrence in the elderly and assess the utility of ultrasonic diagnostic measurements for evaluating aged skin characteristics as a predictor for skin tears.

Baseline data will be collected from all consenting residents on admission to the study. Resident demographic data, comorbidities, medications, Braden Scale mobility and activity score and the collective and individual incidents of skin tear occurrence will be obtained from the facilities data management system. A skin inspection will be conducted to identify the presence of senile purpura, ecchymosis, haematoma, oedema, and previous skin tear scars, which are characteristics associated with skin tears identified in a previous study.

A non-invasive multicomponent device (DermaLab® Combo Cortex Technology, Hadsund, Denmark), will be used to measure the resident's skin thickness, elasticity, moisture, and trans-epidermal water loss and temperature from five sites (bilateral upper and lower extremities, and the abdomen). Sebum and pH measures will be obtained using the non-invasive Sebumeter® (Courage + Khazaka) and Skin-pH-Meter (Courage + Khazaka). Tissue perfusion measurements of the lower limbs will be obtained using a non-invasive 8-MHz Doppler probe (Hedeco Smartdop 30Ex®).

Residents or their legal guardian will be informed of the study and provided with written information. Residents who do not give consent for any reason will not participate in the study. Repeat measurements will be undertaken at 6-months of the resident being recruited to the study.

The key objects of the study are:

1. Identify associations between skin tear occurrence in the elderly and skin structural thickness and elasticity, TEWL, sebum production, skin pH and lower leg vascular perfusion status.
2. Identify associations between skin tear occurrence in the elderly and the presence or not of: senile purpura, ecchymosis, haematoma, oedema and evidence of scarring and the inability of the person to reposition themselves independently.
3. Examine the utility of multi-purpose non-invasive ultrasound technology for determining skin structural thickness and elasticity, TEWL, sebum production, skin pH, and lower leg vascular perfusion status as predictors for skin tears.

It is anticipated that the published findings of this study will influence ongoing assessment of aged care residents and identify those at risk of a skin tears within the Bethanie Group Inc. facilities and other health care services both nationally and internationally.

This study will be conducted by a Doctor of Philosophy student who has been awarded an Australian Postgraduate Award and a Curtin University Postgraduate Scholarship. The study will be undertaken in collaboration with The Bethanie Group and Curtin University. The research is funded by the Wound Management Innovation Cooperative Research Centre (CRC).

If you have any concerns regarding this research in relation to any of your residents please communicate this with the Facility Manager or Research, the Investigator Robyn Rayner on 0406 315 618 or email robyn.rayner@postgrad.curtin.edu.au, Ms Amy Steer, Bethanie's Research and Grants Coordinator, on (08) 6222 9091 or amy.steer@bethanie.com.au or Prof Keryln Carville on 0402792324 or k.carville@urtin.edu.au.

We thank you for your support and assistance in helping Bethanie to undertake this research.

Yours Sincerely,

Robyn Rayner

Research investigator

Telephone number: 0406 315 618

Email address: robyn.rayner@postgrad.curtin.edu.au

Appendix L

Resident Information Sheet

Identification of skin characteristics associated with skin tears in older adults

You are invited to take part in this study. Please take the time to read this information sheet and the attached consent form. If you agree to take part in this study you will need to sign the consent form.

What is this study about?

Skin tears are common injuries that occur as we age. By taking part in this study you will be helping to identify factors that may relate to skin tear occurrence and assist staff to provide appropriate preventive care. This study will use three non-invasive devices to measure skin thickness, elasticity, water loss, pH, temperature, sebum content and blood flow. The test measurements are painless and will take about one and a half to two hours to complete. The test will be performed on the forearms, lower legs and abdomen. The test will be repeated in 6-months' time to determine if changes have occurred in your skin.

How will I be involved?

If you agree to take part in this study, you will have non-invasive testing of your skin using an ultra-sound device, to measure its thickness, elasticity, pH, temperature, sebum content and water loss. A blood pressure recording will be taken from your big toes to determine blood flow to your feet. A probe will be gently applied to the skin of your ankle to determine blood flow from your feet. During these measurements, you will need to sit still for a brief period. The nurse undertaking the measures will remain with you throughout the procedure. The tests will be completed in the privacy of your bedroom. You may also be asked to have photographs taken of the skin of your arms or legs and any skin tears that may occur. Your identity will be protected in these images. If you chose not to have photographs taken you can still participate in the skin testing.

Voluntary participation

It is important for you to know that you do not have to take part in this study. If after agreeing, you change your mind about being involved you may withdraw and any study records containing your information will be destroyed. Your decision to participate will not influence your care at your residential aged care facility in any way.

How will your privacy be protected?

If you decide to take part in this study all information relating to you will remain strictly confidential. To protect your privacy, your name will not be kept on any study records and you will be identified only by a number. The results of this study may be presented at conferences and reported in journals but will not include any personal information about you. In accordance with national research guidelines all study records will be stored for 5 years in a secure location and will then be destroyed.

Who do contact if you have any further questions about the study?

Should you decide to participate in this study or have any further queries please contact either myself (Robyn Rayner) on 0406 315 618, Ms Amy Steer, The Bethanie Group Research and Grants Coordinator on 6222 9091, or my project supervisors, Professor Keryln Carville or Professor Gavin Leslie or Dr Pamela Roberts on 9266 9266.

This project has been approved by the Curtin University Human Research Ethics Committee, approval number RD-23-13, and the Bethanie Research Review Committee. For any ethical concerns regarding this project contact the secretary of the Curtin University Human Research Ethics Committee on telephone number: 9266 2784; email hrec@curtin.edu.au; or write to C/- Office of Research and Development, Curtin University of Technology, GPO Box U1987, Perth WA 6845.

Your participation in this study is greatly appreciated and I thank you for your support.

Appendix M
Study Consent Form

Curtin University of Technology School of Nursing and Midwifery

Project Consent Form

Project Title: Identification of skin characteristics associated with skin tears in older adults

On behalf of -

(Print Full Name of Resident to Participate in the Study)

- I have read the Information Sheet about this study and any questions I have asked have been answered to my satisfaction
- I agree that during participation in the study, photographs can be taken of the skin of the arms or legs and any skin tears that may occur?

Yes ☐ No ☐

- I understand that participation is voluntary and that participants have the right to withdraw at any time without any consequence
- I understand that all information collected is confidential and will not identify the resident in any way
- I Agree that the research data collected from this study may be presented and published, provided that I am not identifiable
- I have been provided with a copy of the Information Sheet for this project and understand that I may contact the researcher if I have any further questions regarding this project

.....

Name of Legal Guardian (if applicable)

.....

Date

.....

Signature of Resident / Legal Guardian

.....

Date

.....

Signature of Researcher

.....

Date