

1 A radiographic analysis of the influence of initial neck posture on cervical
2 segmental movement at end-range extension in asymptomatic subjects

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23

ABSTRACT 200/200

24

25 In the management of neck pain disorders, McKenzie recommends performing
26 neck extension exercises from a fully neck retracted position in order to achieve a
27 maximum range of lower cervical extension. However, no study has investigated
28 the rationale for pre-positioning the neck prior to the extension exercise. This
29 study compared end-range sagittal cervical segmental rotation and translation
30 from three starting positions: the neck in neutral (Ex), retraction (Ret-Ex) and
31 protraction (Pro-Ex). Twenty asymptomatic healthy volunteers were recruited.
32 Lateral radiographs were taken in neutral and at each of the three end range
33 positions and differences in sagittal rotation angles and translation from the neck
34 neutral posture were calculated at each segment. The results indicated that there
35 was a significant difference ($P < 0.001$) in the pattern of the sagittal segmental
36 rotation albeit no significant difference ($P > 0.05$) in the total segmental sagittal
37 rotation among the three conditions. Pro-Ex generated significantly ($P < 0.05$)
38 greater extension range at C1-2 than alternate conditions and Ret-Ex produced
39 significantly ($P < 0.05$) greater extension range at C6-7 than alternate conditions.
40 In contrast, there was no significant difference ($P > 0.05$) in the pattern of the
41 segmental translation values under the three conditions. These indicate initial
42 neck positions can influence cervical segmental movement pattern in extension.

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KEYWORDS

45 McKenzie, Neck, Extension, Segmental movement

46

INTRODUCTION

47

48 Mechanical Diagnosis and Treatment (MDT) is a well-known management
49 strategy for spinal disorders (Jackson, 2001; Gracey et al., 2002; Manca et al.,
50 2007). For neck-related pain the MDT concept utilizes exercise predicated upon
51 a systematic evaluation of pain location and responses to repeated cervical
52 movements (McKenzie and May, 2006). An important aspect of the MDT concept
53 is to identify the direction of neck movement that improves neck symptoms, which
54 is known as the directional preference. Cervical extension is reported to be the
55 predominant directional preference for management of such pain using MDT
56 (Hefford, 2008). Hefford (2008) demonstrated that 12 of 15 (80%) patients with
57 neck related upper limb pain had symptom reduction using neck extension
58 exercises.

59

When prescribing neck extension exercise, emphasis has been placed on
60 performing the extension exercise from a fully neck retracted position (McKenzie
61 and May, 2006). Although the rationale for this is based on clinical experience, a
62 possible biomechanical explanation is that neck extension from a neck retraction
63 position induces greater extension in the lower segments while neck extension
64 from a neck protraction position induces greater movement in the upper-mid
65 cervical region. However, there have been no studies to confirm this.

66

Previously, Haughie et al. (1995) demonstrated that total active neck
67 extension range increased by 10° when neck extension was commenced from
68 erect sitting posture (mimicking a retraction posture) compared with neck
69 extension from natural sitting posture. However, this study measured the total
70 neck extension range with the use of an external cervical range of motion device
71 and it was not clear which segments were influenced by altering the neck
72 starting position. Hence, it is necessary to investigate segmental movements of

73 the whole cervical spine during neck extension, from different neck starting
74 postures, in order to examine which segment(s) are affected by changes of neck
75 starting positions.

76 The purpose of this radiographic study was to compare the pattern of upper
77 and lower cervical movement (sagittal cervical segmental rotation and
78 translation) in full cervical extension when commenced from three different
79 cervical starting positions – neutral, protraction and retraction. .

80

81

METHODS

Subject Group

83 Twenty asymptomatic healthy young volunteers (10 females) with a mean
84 age of 25.3 ± 3.4 years were recruited from advertising in the Sapporo Medical
85 University. Exclusion criteria included pregnancy, claustrophobia, metal implants,
86 and a history of significant cervical spine or shoulder girdle disorders. All subjects
87 were screened with a routine physical examination of range of motion of the neck
88 and upper limbs to ensure normal cervical movements and all subjects had a
89 brief MRI evaluation using sagittal T2-weighted images and axial T2*-weighted
90 images of the cervical spine to detect any evidence of cervical disc disease or
91 congenital anomalies. An orthopedic surgeon experienced in MRI evaluation,
92 inspected all MRI images and no subjects were rejected in this screening
93 process.

94 All subjects were informed of the study design and the radiographic
95 procedures to be used and the risks of radiation and all provided informed
96 consent prior to data collection. Data collection was conducted in Shinoro
97 Orthopedic, Sapporo, Japan. This study was granted ethical approval by the
98 Research Ethics Committee of the Society of Physical Therapy Science, and

99 was conducted in accordance with the Declaration of Helsinki.

100

101 Subject setup and cervical positions

102 Subjects were positioned in standing with the head and neck in a relaxed,
103 neutral resting position, looking straight ahead. The trunk was firmly supported,
104 anteriorly and posteriorly, by a handmade wooden jig positioned at the level of the
105 sternum. Previously it has been shown that repeated neck movements alters the
106 resting posture of the neck, which may ultimately influence the measurement of
107 range of motion in any given direction. (Pearson and Walmsley, 1995). To
108 prevent this, the sagittal rotation angle of the head was set at zero for all starting
109 positions, prior to each movement, and was checked by a specifically designed
110 device, attached firmly to the ear (Figure 1). This device consisted of a bubble
111 spirit level. The head was maneuvered until the bubble was centered, prior to the
112 commencement of each test movement (sensitivity; $0.5\text{mm/m}=0.03^\circ$, accuracy;
113 $\pm 2.5\text{mm/m}=\pm 0.14^\circ$, ED-KEY, EBISU, Niigata, Japan).

114 The subjects were instructed in how to actively move to and hold each of the
115 three test positions; Extension (Ex) - end-range cervical extension starting from a
116 neutral neck posture; Retraction followed by extension (Ret-Ex) - end-range
117 cervical extension starting from a retraction posture; and Protraction followed by
118 extension (Pro-Ex) - end-range cervical extension starting from a protraction
119 posture. All end-range movements (extension, retraction, and protraction) were
120 confirmed by an examiner who applied passive over pressure. Subjects were
121 instructed to extend the neck with a standardized instruction 'bend your head
122 backward as far as you can to look up to the ceiling keeping your mouth open'.
123 Subjects practiced the test positions and tasks five times in preparation for
124 subsequent radiographs.

125 A lateral radiograph was taken in the neutral position and in each end range
126 position of Ex, Ret-Ex and Pro-Ex. The order of testing of each position was
127 randomly allocated between subjects.

128

129 Radiographic analysis

130 Radiographs were taken by the orthopedic surgeon (Y.I.) using standard
131 radiographic techniques with the tube centered on the C5 vertebra. The
132 radiographic film cassette was positioned 150 cm from the tube.

133 The four lateral radiographs for each subject were analyzed from digital
134 images using ImageJ1.6 software (National Institute of Mental Health, Bethesda,
135 USA). From each radiograph, two measurements were taken at each cervical
136 motion segment; a sagittal rotation angle and a translation using methodology
137 previously described (Frobin et al., 2002). Sagittal rotation angles for each
138 segment, from Occiput-C1 to C6-7, were defined as the difference between the
139 angles in each measurement position from those of the neutral position. The
140 degrees of segmental extension compared with the value in the neutral position
141 were described as negative and flexion as positive. Each translation, from C1-2
142 to C6-7, was measured in millimeters and was deemed negative if the projection
143 of the cranial center point of the upper vertebra was located more posteriorly to
144 that of the lower vertebra.

145 The segmental sagittal rotation angle at the Occiput-C1 segment was
146 calculated using a modified Frobin technique (Frobin et al., 2002), where four
147 landmarks on the C1 vertebra (superior and inferior margins of the anterior and
148 posterior tubercles of the atlas,) were identified using an established protocol
149 (Van Mameren et al., 1990; Dvorak et al., 1991; Ordway et al., 1999). The sagittal
150 rotation angle was the angle between the McGregor line (hard palate to the

151 inferior occiput) and a bisector of the four landmarks of C1 (Figure 2).

152 Measurements for the segmental sagittal rotation angle and translation at
153 the C1-2 segment were based on the landmarks of C1 and the two inferior
154 corners of C2 (Figure 2). The angle between C1 and C2 was measured between
155 the line running through the midline of C1 and the line through inferior corners of
156 C2. Translation was defined by the distance between the projection of the
157 midpoint of the midline of C1 and the projection of the midpoint of the line
158 connecting inferior corners of C2 onto the bisector between the two lines.

159 The sagittal rotation angles and the translation at segments from C2 to C7
160 were obtained by marking the two inferior corners of C2 and the corners of each
161 vertebra from C3 to C7 as previously described (Frobin et al., 2002; Wu et al.,
162 2007). The corner points for the C3 to C7 vertebrae were calculated
163 mathematically by finding the midlines of each vertebra. This was defined as a
164 line running through the midpoints between the two anterior and two posterior
165 corners. The bisecting line between two midlines and the perpendiculars from the
166 centers of the adjacent vertebrae were used to calculate the segmental sagittal
167 rotation angles and range of translation (Frobin et al., 2002; Wu et al., 2007)
168 (Figure 3).

169 The defined vertebral landmarks were digitized twice and the mean values of
170 these were used for subsequent analysis.

171

172 Reliability & statistic analysis

173 To assess repeatability of the measurements for cervical sagittal rotation
174 angles and translations measured in extension from a neutral position, one
175 investigator measured the images on two separate occasions. The investigator
176 was blinded to measurements of the first occasion and the order of radiographs

177 in different neck starting positions was changed. $ICC_{(1,2)}$ and the standard error of
178 measurements (SEM) were calculated and Bland-Altman Plots examined for
179 measurement error.

180 A repeated measures ANOVA was used to determine differences in the
181 sagittal rotation angles and translations between Ex, Ret-Ex, and Pro-Ex
182 positions. The Bonferroni test was employed as post-hoc test to examine the
183 differences in segmental sagittal rotation ranges and translations at each
184 segment from the Occiput to C7, as well as the total cervical sagittal rotation..
185 Statistical analysis was performed using SPSS version 18.0 (SPSS Inc., Tokyo,
186 Japan). Statistical significance was attributed to P values less than 0.05.

187

188

RESULTS

189 The $ICCs_{(1,2)}$ for the measurements and SEMs taken from 80 radiographs
190 are presented in Table 1, and can be interpreted as demonstrating good
191 repeatability. Bland-Altman Plots for the variable showing the highest and lowest
192 $ICC_{(1,2)}$ value are presented in Figure 4 (C3-4 Pro-Ex translation) and Figure 5
193 (C4-5 Ex translation), respectively. Visual inspection of these Bland-Altman Plots
194 indicates that measurement errors can be considered random in nature.

195 The values for segmental rotation with standard deviations are presented in
196 Table 2. A repeated measures ANOVA revealed an interaction between position
197 and segment ($P<0.001$). Post-hoc analysis revealed that the extension angle of
198 segmental rotation at C1-2 in Pro-Ex was significantly greater when compared
199 with either Ex ($P<0.05$) or Ret-Ex ($P<0.01$). In addition, the value of extension at
200 C6-7 in Ret-Ex was significantly greater than that of either Ex ($P<0.001$) or
201 Pro-Ex ($P<0.05$). However, there was no significant difference ($P>0.05$) in the
202 total cervical sagittal rotation between the three conditions.

203 The mean values for translation are shown in Table 3. No significant
204 difference ($P>0.05$) was observed in the segmental pattern of translation
205 between the three conditions.

206

207

DISCUSSION

208 This study demonstrated that there were some differences in the pattern of
209 segmental sagittal plane rotation when commenced from different neck starting
210 positions. Significant changes were observed at the C1-2 and C6-7 segments
211 with no significant variations being measured at other cervical segments. The
212 Pro-Ex movement resulted in an increased range of extension motion at C1-2
213 (mean 2.2° , representing 35% more extension) compared with the Ex movement.
214 The Ret-Ex movement resulted in an additional mean 2.8° or up to 54% more
215 extension at C6-7 when compared to the Ex movement. At a first glance, the
216 difference of 2.2° - 2.8° between the different exercise procedures may seem
217 small, but they were statistically significantly. Furthermore these small ranges
218 represent 35%-54% of the segmental extension range of motion at these
219 segments. Such large percentage variation at a segmental level may be
220 important from a clinical perspective. It must also be recognized that such small
221 differences in range of motion may simply represent measurement error (Van
222 Mameren et al., 1990).

223 Interestingly, the two different starting postures affected the C1-2 and C6-7
224 in an apparent inverse way, in that starting in a protracted position resulted in
225 more extension at C1-2 and lesser at C6-7 with the reverse occurring when
226 starting from the retraction position. This altered pattern of segmental movement
227 coincides with the hypothesis that neck extension from neck retraction position
228 induces greater extension in the lower segments while neck extension from a

229 head protraction position induces greater movement in the upper-mid cervical
230 region.

231 These results in this study are not unexpected as it is known that neck
232 protrusion invokes extension in the upper cervical region and flexion in the lower
233 cervical region whereas neck retraction invokes flexion in the upper cervical
234 region and extension in the lower cervical region (Ordway et al., 1999). Wu et
235 al.(Wu et al., 2010) demonstrated that generally, the lower cervical spine
236 contributes greater extension during the initial one third of the extension motion
237 while the middle cervical spine contributes most during the final one third of
238 extension. Hence, when cervical extension is initiated from a protracted position,
239 the pre-flexed lower cervical spine would not achieve maximum extension range,
240 which normally occurs during the initial extension motion. Consequently this may
241 explain the reduced extension range at C6-7 in the movement of Pro-Ex.

242 Wu et al. (2010) did not examine segmental movement at C1-2 during
243 cervical movement, and it is therefore not possible to use their findings to identify
244 a reason why the extension range of C1-2 increased in Pro-Ex and decreased in
245 Ret-Ex. One explanation for this phenomenon may be that paradoxical
246 movements occur at C1/2 during flexion and extension due to the location of the
247 joints of the atlas with respect to the line of gravity of the head and the line of
248 action of the neck flexor and extensor muscles (Bogduk, 2002). Whether the
249 atlas flexes or extends during flexion-extension of the head depends on where
250 the occiput rests on the atlas (Bogduk, 2002). For example, if the neck is first
251 protracted, the center of gravity of the head will come to lie relatively anterior to
252 the atlantoaxial joint. Consequently, the atlas will be tilted into flexion by the
253 weight of the head, irrespective of any action by longus cervicis on its anterior
254 tubercle. However, if the head is retracted, the center of gravity of the head will

255 tend to lie more posterior than when the head is protruded, and paradoxically,
256 the atlas will be squeezed into extension by the weight of the head. Our finding
257 of neck extension from neck retraction position inducing greater extension in the
258 lower cervical spine while neck extension from a head protraction position
259 induces greater movement in the upper cervical spine concurs with this
260 hypothesis.

261 We found no significant difference in the total range of cervical extension
262 starting from each different resting posture. Haughie et al (1995) demonstrated
263 approximately 10° difference in extension range between neck extension from
264 an erect sitting posture and a natural sitting posture. Our results possibly
265 indicate that the increased extension range in the previous study in neck
266 extension commenced from erect sitting posture (mimicking a retraction posture)
267 might have been achieved by increased extension at the cervicothoracic junction
268 rather than cervical segments. Hence, the biomechanical basis for the
269 therapeutic benefits of Ret-Ex may be explained by the movement being
270 induced in the cervicothoracic junction, away from the source of neck pain
271 (Aquino et al., 2009), by relatively fixing the upper cervical spine.

272 Cervical sagittal rotation accompanies posterior translations (Frobin et al.,
273 2002; Reitman et al., 2004; Pickett et al., 2005; Wu et al., 2007) because of the
274 orientation and shape of the zygapophyseal joints below the C2 vertebra. Hence,
275 we expected to find altered segmental translation corresponding with an altered
276 pattern of segmental sagittal rotation. However, we found no such difference in
277 the pattern or value of translation between the different trials of neck extension.
278 However, compared with the means, standard deviations were large, which
279 might explain the lack of difference between different trials. In addition, in the
280 lower cervical segments, posterior translation occurred to a lesser extent than in

281 the middle cervical segments, a finding corresponding with previous studies.

282 The effect of exercise on segmental translation range is conceptually
283 important in the presence of cervical instability, as it would not be appropriate for
284 an exercise to magnify the translation range at a potentially unstable segment. In
285 this study, it was shown that for healthy volunteers, initial neck position did not
286 significantly change the range or direction of segmental translation.
287 Nevertheless further investigation is required to investigate if initial neck position
288 influences segmental translation movements in patients with neck pain disorders
289 with potential instability because of trauma or pathology (Kristjansson et al.,
290 2003; Centeno et al., 2007).

291 This study demonstrated good reliability for the assessment of sagittal
292 rotation range and translation. To date, for the reliable measurement of
293 translation, specialized software has been required and the assessment of
294 translation is generally undertaken in research settings. However, we
295 demonstrated reliable measurement of translation using general measurement
296 software – ImageJ1.6. Hence, this study enables clinicians to measure and
297 assess translation with confidence using this simple software.

298 The present study has some limitations. Measurement did not include the
299 cervico-thoracic junction because radiographically, this region was obscured by
300 the shadow of the shoulder. Hence, it is impossible to evaluate the impact of
301 different neck starting positions on cervicothoracic junction kinematics during
302 neck extension. An alternative method of investigation is required for this
303 objective, such as vertical MRI. In addition, data were provided for end-range
304 extension positions only and did not inform on the movement pattern through
305 range. Different starting postures may potentially affect muscle firing patterns
306 around the neck and upper trunk and thereby influence movement through range.

307 Further studies are required to evaluate real-time changes using combinations of
308 electromyography and real-time visualization of cervical kinematics, for example
309 video fluoroscopy. Finally, all subjects were young and healthy without cervical
310 spinal disorders. It is not possible to directly compare these results with the
311 kinematics of older subjects or those with neck pain disorders, particularly
312 following trauma, who may have segmental instability. Further studies are
313 required to investigate the biomechanics of specific therapeutic exercise in the
314 MDT concept in different patient populations.

315

316

CONCLUSION

317 The present study demonstrated that initial neck posture has differing
318 effects on the pattern of upper and lower cervical segmental movement in full
319 cervical extension in young healthy individuals. These findings support the
320 rationale for retraction followed by extension when exercise aims to influence the
321 lower cervical segments as employed in the MDT concept, although further
322 studies are required in different populations with neck symptoms.

323

324 xx, 06, 2010

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326 **Manual Therapy**327 **Editors**328 **Dear Dr. Ann Moore and Dr. Gwendolen Jull**

329

330 Manuscript title: The influence of initial neck posture on cervical segmental
331 movement at end range extension – normative data with a radiographic analysis

332

333 Thank you very much for the review of our manuscript. Please find the revised
334 manuscript, tables, and figures with changes made according to reviewers'
335 suggestions. Please find a separate document where there are responses for
336 comments from the reviewers. Revised parts in the text were highlighted in red.
337 We believe that this process has strengthened the manuscript.

338

339 Your consideration of this manuscript for publication in Manual Therapy journal
340 will be very much appreciated.

341

342 Your sincerely,

343

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381 CAPTIONS TO FIGURES AND FIGURE LEDGENDS

382 Figure 1. A device with a water level.

383

384 Figure 2. Definitions of the sagittal rotation angle and translation between
385 Occiput-C1, and C1-2.

386 Intervertebral translation between Occiput and C1 vertebra was not defined nor
387 measured.

388 1a; Superior margin of the anterior tubercle of atlas

389 1b; Inferior margin of the anterior tubercle of atlas

390 1c; Superior margin of the posterior tubercle of atlas

391 1d; Inferior margin of the posterior tubercle of atlas

392 2a; Anterior and inferior corner of C2

393 2b; Posterior and inferior corner of C2

394 θ ; Segmental sagittal rotation at Occiput-C1

395 θ' ; Segmental sagittal rotation at C1-2

396

397 Figure 3. Definitions of the sagittal rotation angle and translation from C2-3 to
398 C6-7.

399 2a; Anterior and inferior corner of C2

400 2b; Posterior and inferior corner of C2

401 θ'' ; Segmental sagittal rotation at C2-3

402 θ''' ; Segmental sagittal rotation at C3-4

403

404 Figure 4. Bland-Altman Plot of the Pro-Ex in translation at the C3-4, which has
405 the highest value in $ICC_{(1,2)}$.

406 A; The value of the first measurement (millimetres)

407 B; The value of the second measurement (millimetres)

408 Mean; Mean of the difference between A and B (0.05 mm)

409 SD; Standard deviations of the differences between A and B (0.3 mm)

410

411 Figure 5. Bland-Altman Plot of the Ex in translation at the C4-5, which has the

412 lowest value in $ICC_{(1,2)}$.

413 A; The value of the first measurement (millimetres)

414 B; The value of the second measurement (millimetres)

415 Mean; Mean of the difference between A and B (0.2 mm)

416 SD; Standard deviations of the differences between A and B (1.0 mm)

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421 Aquino RL, Caires PM, Furtado FC, et al. Applying Joint Mobilization at Different
422 Cervical Vertebral Levels does not Influence Immediate Pain Reduction in
423 Patients with Chronic Neck Pain: A Randomized Clinical Trial. *J Man
424 Manip Ther* 2009; 17(2): 95-100

425 Bogduk N. *Physical therapy of the cervical and thoracic spine*. Biomechanics of
426 the cervical spine New York: Churchill Livingstone, 2002; ch, p 26-44.

427 Centeno CJ, Elkins W, Freeman M, et al. Total cervical translation as a function
428 of impact vector as measured by flexion-extension radiography. *Pain
429 Physician* 2007; 10(5): 667-71

430 Dvorak J, Panjabi MM, Novotny JE, Antinnes JA. In vivo flexion/extension of the
431 normal cervical spine. *Journal of Orthopaedic Research* 1991; 9(6):
432 828-34

433 Frobin W, Leivseth G, Biggemann M, Brinckmann P. Sagittal plane segmental
434 motion of the cervical spine. A new precision measurement protocol and
435 normal motion data of healthy adults. *Clin Biomech (Bristol, Avon)* 2002;
436 17(1): 21-31

437 Gracey JH, McDonough SM, Baxter GD. Physiotherapy management of low
438 back pain: a survey of current practice in northern Ireland. *Spine (Phila Pa
439 1976)* 2002; 27(4): 406-11

440 Haughie LJ, Fiebert IM, Roach KE. Relationship of forward head posture and
441 cervical backward bending to neck pain. *J Manual Manipulative Ther*
442 1995; 3(3): 91-7

443 Hefford C. McKenzie classification of mechanical spinal pain: profile of
444 syndromes and directions of preference. *Manual Therapy* 2008; 13(1):

- 445 75-81
- 446 Jackson DA. How is low back pain managed? *Physiotherapy* 2001; 87(11):
447 573-81
- 448 Kaltenborn FM, Evjenth O, Kaltenborn TB, Morgan D, Vollowitz E. Manual
449 mobilization of the joints. The Kaltenborn method of joint examination and
450 treatment. Volume II The spine. , 4th ed. Oslo: Olaf Norlis Bokhandel;
451 2003. p. 33-42.
- 452 Kristjansson E, Leivseth G, Brinckmann P, Frobin W. Increased sagittal plane
453 segmental motion in the lower cervical spine in women with chronic
454 whiplash-associated disorders, grades I-II: a case-control study using a
455 new measurement protocol. *Spine (Phila Pa 1976)* 2003; 28(19): 2215-21
- 456 Manca A, Dumville JC, Torgerson DJ, et al. Randomized trial of two
457 physiotherapy interventions for primary care back and neck pain patients:
458 Cost-effectiveness analysis. *Rheumatology* 2007; 46(9): 1495-501
- 459 McKenzie R, May S. The cervical & thoracic spine mechanical diagnosis &
460 therapy. Vol 1. Raunati Beach: Spinal publications New Zealand Ltd;
461 2006. p. 58-60, 235-6.
- 462 Ordway NR, Seymour RJ, Donelson RG, Hojnowski LS, Edwards WT. Cervical
463 flexion, extension, protrusion, and retraction. A radiographic segmental
464 analysis. *Spine* 1999; 24(3): 240-7
- 465 Pearson ND, Walmsley RP. Trial into the effects of repeated neck retractions in
466 normal subjects. *Spine (Phila Pa 1976)* 1995; 20(11): 1245-50; discussion
467 51
- 468 Pickett GE, Rouleau JP, Duggal N. Kinematic analysis of the cervical spine
469 following implantation of an artificial cervical disc. *Spine (Phila Pa 1976)*
470 2005; 30(17): 1949-54

- 471 Reitman CA, Mauro KM, Nguyen L, Ziegler JM, Hipp JA. Intervertebral motion
472 between flexion and extension in asymptomatic individuals. Spine (Phila
473 Pa 1976) 2004; 29(24): 2832-43
- 474 Van Mameren H, Drukker J, Sanches H, Beursgens J. Cervical spine motion in
475 the sagittal plane (I) range of motion of actually performed movements, an
476 X-ray cinematographic study. European Journal of Morphology 1990;
477 28(1): 47-68
- 478 Wu SK, Kuo LC, Lan HC, et al. The quantitative measurements of the
479 intervertebral angulation and translation during cervical flexion and
480 extension. European Spine Journal 2007; 16(9): 1435-44
- 481 Wu SK, Kuo LC, Lan HC, Tsai SW, Su FC. Segmental Percentage Contributions
482 of Cervical Spine During Different Motion Ranges of Flexion and
483 Extension. Journal of Spinal Disorders and Techniques 2010;
484
485