THE ACUTE RESPONSE OF THE NUCLEUS PULPOSUS OF THE CERVICAL INTERVERTEBRAL DISC TO THREE SUPINE POSTURES IN AN ASYMPTOMATIC POPULATION

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INTRODUCTION

The mechanisms underlying chronic neck pain are not always clear and may be multifactorial, including for example, mechanical, neuropathic and/or psychosocial factors (Dewitte et al., 2016; Evans, 2014; McLean et al., 2010). One source of cervical pain may be the intervertebral disc and in particular, a posteriorly displaced nucleus pulposus has been associated with spinal pain (Kolber and Hanney, 2009). It has, however, been noted that there is also a relatively high prevalence of abnormal MRI findings of the cervical spine in asymptomatic individuals (Kato et al., 2012; Nordin et al., 2008).

Previous studies have found a significant correlation between a forward head posture and the incidence of neck and inter-scapular pain (Harman et al., 2005; Falla et al., 2007; Yip et al., 2008). This is of particular importance because a high percentage of our daily lives, more so than any time in our past, is now spent sitting, e.g. in the work place or domestic environment, during leisure time or commuting (Owen et al., 2010). This sitting posture usually involves either a protruded head posture, such as when using a computer, or a flexed head posture, such as when reading a book placed at chest level. The common theme in both these postures is flexion of the lower cervical spine.

Studies of the lumbar spine have shown that flexed spinal postures cause posterior migration of the nucleus pulposus (NP) of healthy intervertebral discs (Fredericson et al., 2001; Lee et al., 2009; Parent et al., 2006; Kolber and Hanney, 2009). This ability of spinal disc position to be manipulated by body posture is described by the dynamic disc model (DDM), and its theory was strongly promoted by Cyriax (1953) and McKenzie

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(1981). This biomechanical principle explains that an intervertebral disc that has maintained an intact annulus fibrosis, responds to compressive loading of the spine in a predictable directional manner. More specifically, it suggests that flexion of the spine causes compression of the anterior portion of the intervertebral disc, resulting in posterior migration of the NP, while extension of the spine has the reverse impact, resulting in anterior migration of the NP. With this biomechanical reasoning, McKenzie (1981) developed a therapeutic technique aimed at improving the position of displaced NP migrations through various postures and with specific loaded exercises. This has become popular with physiotherapists as a technique to manage spinal pain and, in the case of chronic low back pain, evidence suggests that there may be a minor benefit of this approach compared to some other standard therapies (Lam et al., 2018). Research relating to the McKenzie technique for neck pain, however, remains very limited (Gross et al., 2016). Consistent with the hypothesis of the traditional McKenzie approach, studies investigating the lumbar spine have found that, in discs that have retained their water content, there is movement of the anterior and posterior NP that correlates with extension and flexion of the spine respectively (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009). This has not been demonstrated conclusively in the cervical spine.

There are distinct variations between the morphological structures of cervical and lumbar discs. These differences may potentially affect the cervical disc’s ability to respond to biomechanical loads in the same manner as has been shown in the lumbar spine (Beattie et al., 1994; Fredericson et al., 2001; Alexander et al., 2007; Kolber and Hanney, 2009). McKenzie theorised that in order for the NP to migrate in a predictable

manner, it required the disc to have an intact annular wall, providing it with a hydrostatic pressure (McKenzie, 1981). In contrast to an intact lumbar disc annulus (Galante, 1967; Marchand and Ahmed, 1990), the posterolateral aspects of the cervical disc annulus are devoid of any annular tissue (Mercer and Bogduk, 1999). This is primarily due to the presence of uncovertebral clefts that pierce through the lateral sections of the outer disc, disrupting the annulus in this region. There is also a natural discontinuation of the posterolateral fibres of the cervical disc annulus, with this area being covered by periosteofascial tissue only (Mercer and Bogduk, 1999). A further variation between these two structures is the significant loss of water content within the cervical disc nucleus by the early twenties, this being replaced by a fibrocartilaginous core (Mercer and Bogduk, 1999). This is in comparison to the lumbar disc which maintains a much higher water content within its gelatinous NP (Kraemer et al., 1985). The loss of the cervical disc's water content may affect its malleability during spinal loading.

To date, there has only been one published *in vivo* study which has used MRI to assess the effects of different cervical postures on NP migration. Kim et al. (2017) used MRI to investigate the effect of cervical extension on the position of the NP in cervical discs in ten young, healthy male participants (age 22.4 ± 1.64 years). They found that both the anterior and posterior NP margins remained unchanged relative to the vertebral body, but moved anteriorly with respect to the posterior disc margins in extension. In the current study, it was considered important to investigate the effect of cervical flexion as well as extension due to the potential implications on the health of the cervical disc with common prolonged, flexed sitting postures**.** The aim of this study was therefore to

assess the position of the NP in both flexed and extended cervical postures in relation to the posterior vertebral margins.

MATERIALS AND METHODS

Participants

Twenty five asymptomatic participants (10 males and 15 females, age 33.7 ± 9.1 years, age range 21-49 years) took part in this study. All participants were free from any history of neck pain lasting more than 24 hours in the last 12 months and had experienced no more than one incidence of neck pain in a one-month period.

Participants provided their written, informed consent and completed an MRI safety questionnaire to ensure there were no health and safety reasons for their exclusion from the study. This study conformed to the latest revision of the Declaration of Helsinki and procedures were approved by the University ethics committee.

Procedure

Two protocols are described in the subsequent methods. The first involved reliability testing of the measurement technique, involving cervical MRI scans from a subgroup of 15 participants. The second involved experimental testing using the images of 25 participants for the assessment of posterior NP position with the cervical spine in three different postures. Time constraints and the availability of the testers restricted the number of participants who were able to be included in the initial reliability analysis. In all cases, testing was carried out on the C5-6 and C6-7 discs. These disc levels were chosen because a higher incidence of disc degeneration and disc prolapse has been shown to occur at these levels (Matsumoto et al., 1998).

Magnetic Resonance (MR) imaging protocol for all testing

MRI scans were performed using an Esaote 0.2 T MR imaging scanner. An initial scout scan was performed lasting approximately 1 minute and 38 seconds. This was followed by a coronal scan lasting approximately 30 seconds. The purpose of these two scans was to ensure imaging of the correct section of the cervical spine. Finally, conventional spin echo sagittal images were obtained using the following settings: T1:TR/TE/Nex: 650 ms/24 ms/ 3; slice thickness 4 mm, 0.4 mm spacing, FOV 260 x 260, image matrix 256 x 256, 75% phase field of view. This final scan lasted approximately 6 minutes and 30 seconds and provided the images from which measurements were taken. Files were exported in DICOM format and subsequently analysed using Osirix (Pixmeo, Geneva) and ImageJ (Rasband, 1997-2018) analysis software.

Reliability testing

Inter-rater and intra-rater reliability testing was performed to assess the Principal Investigator's (PI's) ability to measure the posterior C5-6 and C6-7 NP on sagittal view magnetic resonance images with the cervical spine in a neutral position. The PI is a Band 8a and McKenzie accredited physiotherapist with over thirteen years of musculoskeletal clinical experience. To assess inter-rater reliability, both the PI and a consultant head and neck radiologist separately recorded the position of the C5-6 and C6-7 posterior NP on the cervical MR images of 15 asymptomatic participants (seven males and eight females, age 33.7 ± 9.2 years, age range 21-50 years). The PI also recorded the position of the posterior C5-6 and C6-7 discs from the same images on two separate days, approximately seven days apart, in order to assess intra-rater reliability. All scans were

completed with the cervical spine placed in a neutral position. Both the PI and radiologist were blinded to the measurements until all measurement testing had been completed by both testers.

Assessment of posterior NP position

Data collection and measurement were carried out by the PI. The C5-6 and C6-7 disc nucleus for each participant were initially scanned in supine, with a thin mat placed underneath the participant's head for comfort. Following this, scans in cervical flexion and extension were performed (Fig. 1).

Fig. 1. Participants positioned in supine with their cervical spines placed in neutral (A), flexion (B) and extension (C) on the MRI scanner.

Wedges were used to position the cervical spine (Fig. 1), and were also placed under the participants' legs, and in some cases lower back, to reduce discomfort during scanning. When moving into cervical flexion and extension, participants were asked to position themselves at the end of their range of motion to the extent that this was comfortable and possible within the MRI cervical coil. The order of scanning remained the same for all participants. This was to maintain the same direction of movement of the disc, thereby allowing for a more consistent measurement comparison between positions.

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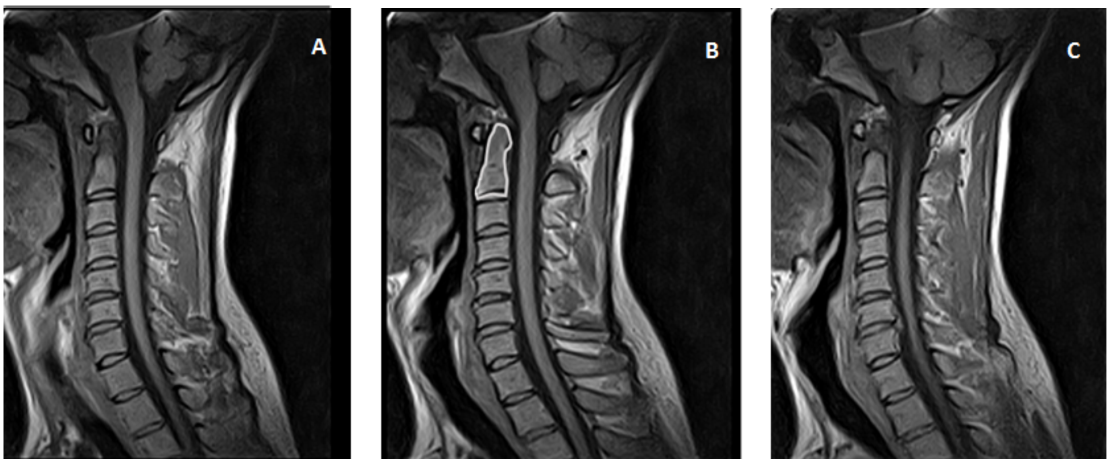
The scout and coronal scans were repeated following each change in position, meaning that participants were in position for approximately 2-3 minutes before each final scan. Each scan was then measured three times, with the mean measurement used in the analysis.

Disc measurement for all testing

The border of the nucleus was identified as the boundary between high- and low-signal areas (Kim et al., 2017). This identification was done manually by the tester. Measurements were taken from the mid-sagittal slice, identified as the slice which visualised the entire length of the C2 vertebral body (Fig. 2). In cases where the shape of the C2 body was similar between two slices, the slice demonstrating the greatest width of the upper spinal cord was used.

Fig. 2. Three consecutive mid-sagittal slices of the cervical spine (A), (B) and (C). Slice (B) demonstrates the entire length of the C2 vertebral body (outlined in white). This identifies the mid-sagittal slice, and therefore the slice to be used for measurement.

The position of the mid-posterior section of the disc NP was measured relative to a line passing through the mid-section of the posterior ends of the vertebral bodies which



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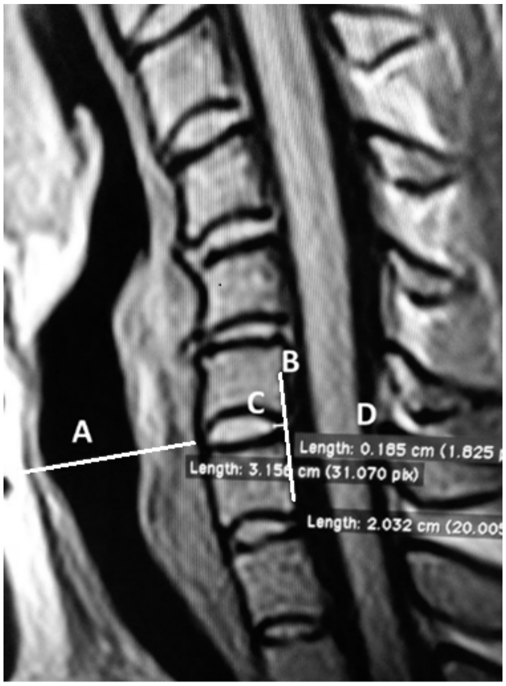
were superior and inferior to the disc (Fig. 3). This technique is very similar to the one described in Fredericson et al. (2001), comparing changes in posterior disc bulging in flexion and extension of the lumbar spine. The measurement was recorded as a negative number if the mid-posterior section of the NP fell posterior to this line, and as a positive if it fell anterior to this line. If the posterior NP fell exactly on the line, the measurement was recorded as zero millimetres.

Fig. 3. Sagittal plane MRI image of the cervical spine in a neutral position. The near horizontal line (A) indicates the C6-7 disc level. The near vertical line (B) connects the approximate mid- section of the vertebral body above and below the C6-7 disc. The short, near horizontal line (C) represents the distance (given in box (D)) from the posterior NP to the posterior vertebral bodies.

To assess the change in neck position between postures, the intersegmental angle for each disc was defined as the angle between the superior border of the inferior vertebra and the inferior border of the superior vertebra. These borders were drawn by



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connecting the anterior and posterior corners of the endplates in each case (Kim et al., 2017; Parent et al., 2006). The angle was taken to be positive if the acute angle was posterior to the spine and negative if anterior.

Results for reliability testingThere were no statistically significant differences found between the two testers' measurements at either the C5-6 or the C6-7 level and the intra-class correlation coefficients (ICCs) indicated good to excellent inter-tester reliability with an ICC of 0.79 at C5-6 (95% confidence interval [CI] [0.44, 0.93]) and an ICC of 0.90 at C6-7 (95% CI [0.72, 0.97]). The standard errors of measurement (SEM) were 0.55 mm and 0.35 mm for C5-6 and C6-7 respectively.

Intra-rater reliability testing also showed no significant difference between measurements at either C5-6 or C6-7 and the ICCs indicated excellent reliability for both C5-6 (ICC 0.91, 95% CI [0.71, 0.97]) and C6-7 (ICC 0.94, 95% CI [0.83, 0.98]). In this case, the SEMs were 0.37 mm and 0.26 mm for C5-6 and C6-7 respectively. The intra-rater reliability results were comparable to those found for disc measurements in similar research (Alexander et al., 2007; Kim et al., 2017).

Statistical analyses

A one-way repeated measures ANOVA was conducted to determine whether there were significant, within-participant differences in posterior NP position between supine cervical spine postures in neutral, flexion and extension. Similar one-way repeated

measures ANOVAs were conducted to investigate the change in segmental angle between postures. In general, the data were deemed normally distributed as assessed by the Shapiro-Wilk test, with the exception of the data for the measurements taken in extension for C5-6 and in flexion for the C6-7 disc, and for the angle data in neutral for C6-7. ANOVAs were still used for the analysis since studies have reported no serious Type I errors introduced by non-normality on the significance levels of the F-test (Glass, 1972). In addition, further analysis of the data showed the results demonstrated normal skewness scores and Mauchly's test of sphericity indicated that the assumption of sphericity had not been violated in any case. In the case of a significant main effect, pairwise comparisons using a Bonferroni adjustment were performed. The results of mixed-factor ANOVAs showed that there was no significant main effect of sex or interaction between sex and posture for either the C5-6 or C6-7 discs. The data for both sexes was therefore combined for the subsequent analysis. Data are presented as means ± standard deviation (SD) and statistical significance was set at $p \leq 0.05$. The statistical analysis was carried out using SPSS (version 25.0).

RESULTS

At least one positional image from seven participants was deemed unusable due to poor image quality caused by the cervical coil. Only participants with readable images in all three cervical positions were used in order to ensure a balanced design. This left images from 18 participants (eight males and ten females) available for data analysis.

A change in cervical position elicited statistically significant changes in posterior NP position for both the C5-6 disc ($F(2, 34) = 7.52$, $p = 0.002$) and the C6-7 disc ($F(2, 34) =$

11.34, $p < 0.001$). At C5-6, the posterior NP position was significantly different in flexion compared with extension and there was a trend for a difference between flexion and neutral. At C6-7, the posterior NP position was significantly different in flexion compared with both neutral and extension (Table 1). These results therefore indicate posterior migration of the NP with a flexed head position. There was no significant difference found between neutral and extension at either level (Table 2). The number of discs that demonstrated movement in each direction between the postures is shown in Table 3.

Disc level	Cervical position	Position of posterior NP (mm)
C5-6	Neutral	0.19 ± 1.32
	Flexion	-0.47 ± 1.14

	Extension	0.63 ± 1.29†
C6-7	Neutral	0.71 ± 0.89
	Flexion	-0.29 ± 1.29*
	Extension	0.31 ± 1.21†

Table 1. Posterior nucleus pulposus (NP) position (mean ± standard deviation (SD)) in relation to the posterior vertebral bodies at both disc levels in the three cervical postures.* denotes significant difference from neutral and † denotes significant difference from flexion ($p < 0.05$).

Disc level	Comparison of cervical positions	Difference in posterior NP positi (mm)
C5-6	Neutral vs Flexion	-0.66 ± 1.08
	Neutral vs Extension	0.44 ± 1.06
	Flexion vs Extension	1.10 ± 1.45
C6-7	Neutral vs Flexion	-1.00 ± 0.93
	Neutral vs Extension	-0.40 ± 0.92

	Flexion vs Extension	0.59 ± 0.82	203	0.0 2

Table 2. Measurement (mean ± standard deviation (SD)) and % difference between posterior nucleus pulposus (NP) position in relation to the posterior vertebral bodies at both disc levels.

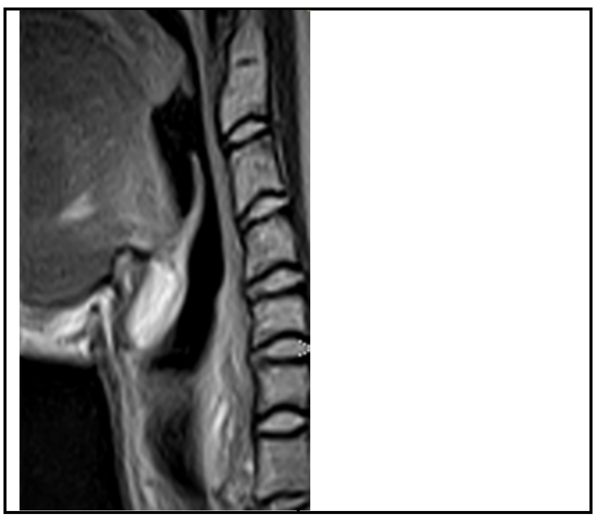
Disc level	Comparison of cervical positions	Posterior NP moved backwards	Posterior NI forwards
C5-6	From Neutral to Flexion	12 (67%)	4 (22%)
	From Flexion to Extension	7 (39%)	11(61%)
C6-7	From Neutral to Flexion	16 (89%)	2 (11%)

	From Flexion to Extension	2 (11%)	15 (83%)

Table 3. Number of discs (and percentage of total [n=18]) in which the nucleus pulposus (NP) showed movement in each direction, relative to the posterior vertebral bodies, following changes in posture.

Fig. 4. MRI of the cervical spine in neutral (A) and flexion (B). The dotted line indicates the outer border of the nucleus pulposus at the C5-6 disc level. These images indicate posterior migration of disc material in the flexed position when compared to neutral. NP denotes the posterior nucleus pulposus.

A change in cervical position was associated with a change in intersegmental angle for both the C5-6 disc ($F(2, 34) = 18.811$, $p < 0.001$) and the C6-7 disc ($F(2, 34) = 10.978$, $p <$



0.001). For both discs, there was a significant difference between the angles during flexion compared with both neutral and extension (Table 4). In all cases, the change in angle was in the expected direction. There was no significant difference found between neutral and extension at either level.

Disc level	Cervical position	Disc intersegmental angle

C5-6	Neutral	0.78 ± 5.18
	Flexion	-4.75 ± 5.55*
	Extension	2.88 ± 6.05†
C6-7	Neutral	4.09 ± 5.30
	Flexion	-0.69 ± 7.28*
	Extension	2.98 ± 5.95†

Table 4. Disc intersegmental angle (mean ± standard deviation (SD)) in the three cervical postures. The angle was taken to be positive if the acute angle was posterior to the spine (e.g. in highly extended position) and negative if anterior (e.g. in highly flexed position).* denotes significant difference from neutral and † denotes significant difference from flexion ($p < 0.05$).

DISCUSSION

The findings from this study suggest that a flexed head posture causes posterior migration of the NP compared to both a neutral (at C6-7) and extended head posture (at both the C5-6 and C6-7 disc levels) (Tables 1 and 2). Although the changes in posterior NP position were significant overall, it was noted that at C5-6, the posterior NP moved in the opposite direction to that expected for 20-40% of participants, and at C6-7 for 11% of participants (Table 3), indicating some differences in response both between individuals and between disc levels. The variation between disc levels may be due to the

limited sample size within this study and Kim et al. (2017) conversely found movement of the NP in the opposite direction to that expected for more discs at the C6-7 level than at C5-6. Studies of both the cervical (Kim et al., 2017) and lumbar spine

(Edmondston et al., 2000) have found that the NP does not always move in the anticipated direction following changes in posture, and the authors suggested that degenerated discs may particularly move more unpredictably, but this behaviour was also observed in discs without apparent degeneration, as in the current study.

While bearing these individual differences in mind, the overall significant differences in posterior NP position are consistent with the concept of the DDM in the cervical spine and show that, despite the early fibrotic changes that occur in the disc and its discontinuous outer annular layer (Mercer and Jull, 1996; Mercer and Bogduk, 1999), the cervical disc may still retain a hydrostatic pressure, allowing the NP to adjust its position according to the direction of pressure applied to it. These results are consistent with previous research on the lumbar spine in asymptomatic participants (Fennell et al., 1996; Alexander et al., 2007) with regards to the direction of movement of the NP in flexed and extended spinal postures. They also agree with *in vitro* studies using human cadavers and porcine specimens, which show convential hydrostatic behaviour within healthy cervical discs, with flexion increasing stresses and, in some cases, causing migration of the posterior disc (Skrzypiec et al., 2007; Scannell and McGill, 2009).

Kim et al. (2017) recently used MRI to investigate the effect of cervical extension on position of the NP of the cervical discs in asymptomatic males. Consistent with the current study, their results did not show any change in position of the NP margins in

relation to the vertebral bodies between neutral and cervical extension. They did, however, report significant anterior migration of the NP margins within the intervertebral disc itself at the C3-4 to C6-7 levels.

In neutral, the posterior C5-6 and C6-7 NP was measured as sitting anterior to the posterior vertebral bodies. This is in contrast to flexion, in which the nucleus had displaced posteriorly in relation to the corresponding posterior vertebral segment. Although the magnitude of the difference was relatively small, over time a sustained flexed position may lead to increased pressure to this area and may potentially cause spinal pain due to pain sensitive neural structures located in close proximity to the posterior cervical disc; however, the clinical consequences of the results were beyond the scope of this study.

No significant difference was found between the posterior NP position in neutral and extension at either level, possibly reflecting the similar intersegmental angles, indicating limited change in lower neck position, between the two positions. This may have been partly due to the cervical coil and scanner bed affecting the degree of lower cervical extension that was physically achievable, meaning that it was not always end of range.

A limitation of the study was the relatively low magnetic field strength of the MRI scanner, which affects the signal-to-noise ratio, contrast and resolution (Botchu et al., 2018), and this was reflected in a number of unusable scans due to image quality. Ideally participants would also have been scanned in a load-bearing posture as there are known to be differences in spinal measurements between loaded and unloaded positions (Botchu et al., 2018; Hansen, 2017). The MRI scanner used in this study includes a tilting

gantry for scanning in weight-bearing positions and it was originally intended that participants would be scanned in an upright sitting position; however this approach was found to result in very poor image quality and therefore was not considered appropriate. As a result, all scans were performed in supine, which makes direct transfer of these findings to occupational postures difficult. Further research carried out in an upright position (and in an MRI scanner with higher field strength) would therefore be beneficial. Nevertheless, it is interesting to note that the change in disc position between cervical postures occurred in the space of a few minutes. Furthermore, one might assume that a flexed and extended head posture in sitting might produce greater changes in disc position compared to lying due to the effects of load. It is acknowledged, however, that the changes in posterior NP position, although statistically significant, were relatively small, and that the differences in disc intersemental angles between flexion and extension were also of limited magnitude.

In conclusion, changes in head posture resulted in significant movement of the posterior NP at the C5-6 and C6-7 disc levels. In line with the dynamic disc model theory, flexion of the cervical spine caused posterior migration of the posterior NP when compared to neutral, while extension of the cervical spine caused reversal of this posterior migration. It should be noted, however, that there was some variation in response, both between individuals and between disc levels.

Conflicts of interestThere is no conflict of interest for this study.

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