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Original Research—CME

Effects of Cervical Extension on Deformation of Intervertebral Disk and Migration of Nucleus Pulposus

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Abstract

Background: We theorized that active cervical extension should influence the position of the nucleus pulposus (NP) within the intervertebral disk (IVD) in the sagittal plane. Although several studies on the lumbar IVD have been conducted, there are no quantitative data for in vivo positional changes of the NP in the cervical IVD.
Objective: To evaluate the influence and mechanism of cervical extension on the deformation and migration of IVD and NP in the sagittal plane and understand underlying mechanisms of the extension maneuver.
Design: Asymptomatic subjects underwent magnetic resonance imaging while supine with their cervical spines in neutral and extended positions.
Setting: Academic medical center.
Participants: Ten young, healthy male participants (age range 19-30 years; mean 22.4 $\pm$ 1.64 years).
Methods: T2-weighted sagittal images from C3-C4 to C6-C7 of subjects in both neutral and extension positions were analyzed.
Main Outcome Measurements: Deformation of IVD and positional change of NP were quantified and compared between neutral and extension positions. Intersegmental angles between vertebrae, horizontal positions of anterior and posterior IVD and NP margins, IVD outer and inner heights, and sagittal morphology of NP were quantified and compared between the neutral and extension positions. Correlations between the measured parameters and segmental extension angle were also investigated.
Results: Anterior and posterior IVD margins moved posteriorly with respect to the vertebral body in extension. Both NP margins remained unchanged relative to the vertebral body but moved anteriorly with respect to the IVD. IVD outer and inner heights in the anterior region increased in extension, and morphological changes of the NP were less noticeable when compared with its relative migration within the IVD. Most of the intradiskal changes were linearly correlated with the segmental extension angle.
Conclusions: Cervical extension induces anterior migration of the NP away from the posterior disk margin and may have a clinical effect on diskogenic neck pain resulting from internal disk disruption.
Level of Evidence: Not applicable.

Introduction

Pain originating from the cervical spine is the second most prevalent pain reported among musculoskeletal problems in modern society after low back pain [1,2]. Epidemiologic studies have shown that the 12-month prevalence of neck pain ranges from 30% to 50% [3-7], and neck pain has been ascribed mainly to degenerative changes and the resultant structural abnormalities in the spinal column, mostly at the facet joints and intervertebral disk (IVD) [8-14]. Among the patients with chronic neck pain, the reported prevalence rates of facetogenic and diskogenic pain ranged from 39% to 55% [8,10,15,16] and from 16% to 20% [8,17,18], respectively.

Although much of the exact mechanism of pain production remains unclear [8,14], it is believed that internal disk disruption such as fissures or tears in the annulus fibrosus (AF), which precedes disk herniation, is thought to be associated with cervical diskogenic pain [12,19,20], whereas herniation of the nucleus pulposus (NP) is believed to play a role in development of cervical radicular pain by irritating the cervical nerve root mechanically or chemically [9,14,21,22]. These types of pain resulting from disruption or displaced tissue within the intervertebral segment collectively were termed a

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derangement syndrome by McKenzie in his conceptual model [19].

Cervical extension maneuvers, as part of the McKenzie approach that uses directional preference of treatment, have been used widely to treat the disk derangement [19,20,23-25], based on the theorized model that the NP moves anteriorly within the IVD in the extended cervical spine, thus reducing pressure on the painful structures in the posterior region. This mechanism might be applicable to the lumbar spinal pain and its treatment using the McKenzie approach, because there exist some lumbar studies in which the authors reported deformation of the IVD and/or migration of the NP in vivo between different spinal positions [26-30], which makes this explanation somewhat likely. To our knowledge, however, there has been no such conclusive evidence derived from quantitative measurement on the cervical disks.

Instead, as Mercer and Jull pointed out [31], many of the clinical studies in the literature discussing the McKenzie model have relied on the underlying assumption that the cervical disks are virtually similar with the lumbar disks, not only structurally but also with regard to the clinical aspects such as pain production mechanism and degenerative processes. Other studies, however, have shown that the cervical disks are distinctly different from the lumbar disks in terms of their chemical composition, morphology, structure, and biomechanics, mainly because of the different functional requirements of the cervical and lumbar spines [31-35]. For this reason, it would be unwise to postulate, as Donelson [36] did, that a rationale similar to that behind the lumbar extension, which essentially is directional preference resulting from anterior migration of the NP, would exist with extension in the cervical spine as well.

Therefore, as an initial step to understand underlying mechanisms of the extension maneuver, this study was designed to quantitatively investigate deformation and displacement of the IVD and NP induced by cervical extension using T2-weighted magnetic resonance imaging (MRI) of young healthy male subjects. It is hypothesized that cervical extension would cause intradiskal deformation and resultant displacement of the NP in anterior direction. To verify this, we compared outer and inner heights of the IVD, horizontal positions of anterior and posterior margins of the IVD and NP, horizontal thicknesses of the AF, and sagittal morphology of the NP between the neutral and extended spinal postures at C3-C4, C4-C5, C5-C6, and C6-C7.

Methods

This study was approved by the institutional review board of Seoul National University Hospital and conducted in the Seoul National University Hospital.

Subjects

MRI scans were obtained from 10 young, healthy male participants (age range 19-30 years; mean 22.4 $\pm$ 1.64 years), with a mean height and weight of 170.8 $\pm$ 6.2 cm and 65.8 $\pm$ 4.4 kg, respectively. Only young and healthy subjects were included for better observation and quantification of changes, based on the presumption that the movement of NP would less likely be observed in older people or patients with pathologic conditions. The subjects were free of pain in the head, neck, shoulder girdles, or upper chest for the past 6 months and had no history of pain in the listed areas requiring medical consultation or that resulted in occupational or recreational activities being limited for more than a day. For safety purposes, only those who did not develop dizziness or pain in extension of their cervical spines for 3 minutes were included in our subjects. Because a subject's upper body had to fit into a space limited by a radiofrequency coil and elevating pad (see the section to follow), subjects heavier than 95 kg were excluded. All participants gave informed consent approved by the institutional review board of Seoul National University Hospital.

MRI-Acquisition Procedures

Each subject's entire cervical spine was scanned in both neutral and extended positions while the subject was supine in a 3T MRI system with a radiofrequency neck coil (Magnetom Trio, Siemens Medical Solutions, Erlangen, Germany). T2-weighted sagittal images were taken with 4000 milliseconds of repetition time and 104 milliseconds of echo time in a 28-cm of field of view with 448 $\times$ 448 matrix. The slice thickness was 3 mm with no gap.

To enable cervical extension while the patient was lying on the scanner table, the subject's upper body was placed on a flat, 50-mm-thick polyurethane foam pad (Figure 1). The neutral position was achieved by supporting the subject's head with another pad so that his ear canal could be horizontally aligned with the center of his shoulder joint, whereas the extension was attained by removing the head-supporting pad. The neutral position was imaged first to avoid the residual effects of cervical extension, such as deformation of the IVD, which might occur if the extension position was imaged first.

Quantitative Analysis of Magnetic Resonance Data

All parameters described in the following sections were measured at each disk level on the mid-sagittal images via MicroDicom software (MicroDicom, Sofia, Bulgaria). To avoid interobserver error, one author (S.I.K.) measured all parameters. Intraobserver error

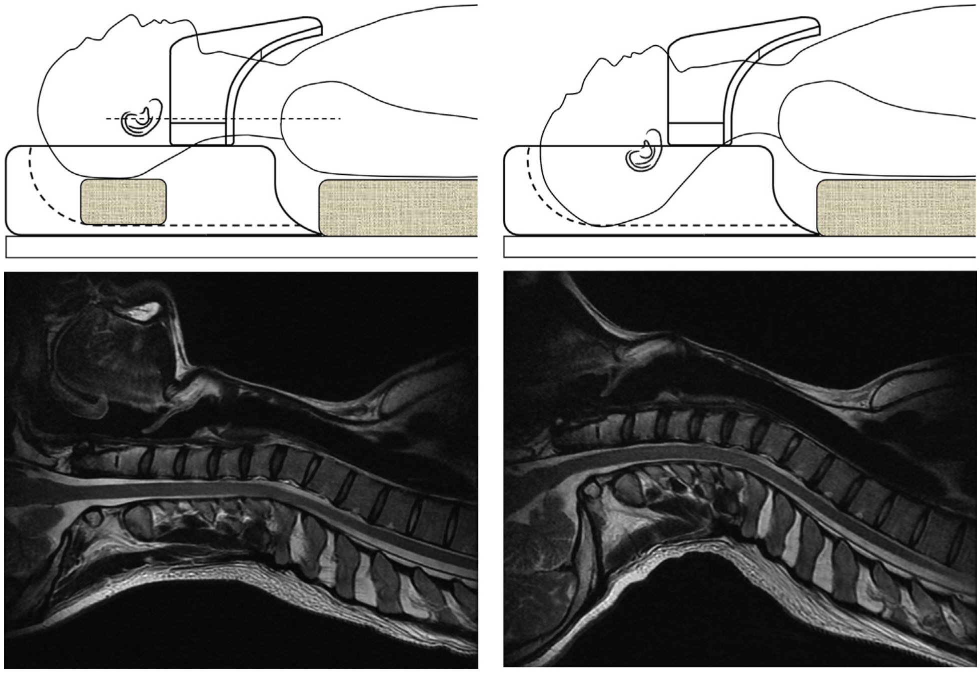

Figure 1. Postures for acquiring T2-weighted sagittal images of neutral (left) and extended (right) cervical spines in supine position.

(coefficient of variation) was assessed by performing 3 repeated measures of the posterior AF thickness at a randomly selected disk level of each subject for both neutral and extension positions. Mean values were calculated. Measurements were conducted in randomized order to exclude influence of the rater's memory. A high level of intrarater reliability was achieved with an intraclass correlation coefficient of 0.899 with 95% confidence interval (0.745-0.971) for neutral and 0.767 with 95% confidence interval (0.485-0.928) for extension. The corresponding standard error of measurement was 0.26 mm for neutral and 0.29 mm for extension, and the minimal detectable change was 0.73 mm for neutral and 0.81 mm for extension.

Segmental Extension Angle

To quantify the amount of angulation between 2 adjacent vertebrae at each disk level when moving from neutral to extension, first an intersegmental angle was defined as the angle between the superior border of the inferior vertebra and the inferior border of the superior vertebra. The superior or inferior border was drawn by connecting the anterior and posterior ring apophyses on the sagittal image (Figure 2A). Then, the difference of the intersegmental angles between neutral and extension was defined as a segmental extension angle, which is equivalent to the range of motion between the 2 states. The superior border of the inferior vertebra was used as a reference for determining the anatomical orientation of the IVD in question; the direction parallel to this line would be described as horizontal and perpendicular as vertical.

Outer and Inner Heights of IVD

To quantify external deformation of the IVD, the outer heights defined as vertical distances between upper and lower boundaries of IVD were measured at one-fourth, one-half, and three-fourths of the way between the anterior and posterior margins of an IVD (Figure 2A). To quantify how much of the NP occupied the intradiskal spaces at each measurement location, IVD inner heights defined as vertical distances between upper and lower boundaries of NP were also measured at the same positions. NP boundaries were identified by the interfaces between high- and low-signal areas on MRI.

Horizontal Positions of IVD and NP Margins

To quantify the deformation and displacement of IVD and NP, horizontal positions of anterior and posterior margins of IVD and NP were measured from the posterior vertebral border which was defined as a line connecting the posterior tips of superior and inferior apophyses of the inferior vertebra (Figure 2A). By calculating differences of the horizontal positions between IVD and NP margins in the anterior and posterior regions, respectively, we also obtained and compared anterior and posterior AF thicknesses between the neutral and extension positions.

Relative Position and Morphology of NP

To quantify the morphologic changes of NP on the sagittal plane, a segmented NP contour was generated from spline interpolation of the 16 points on NP boundary that divided the horizontal NP length into

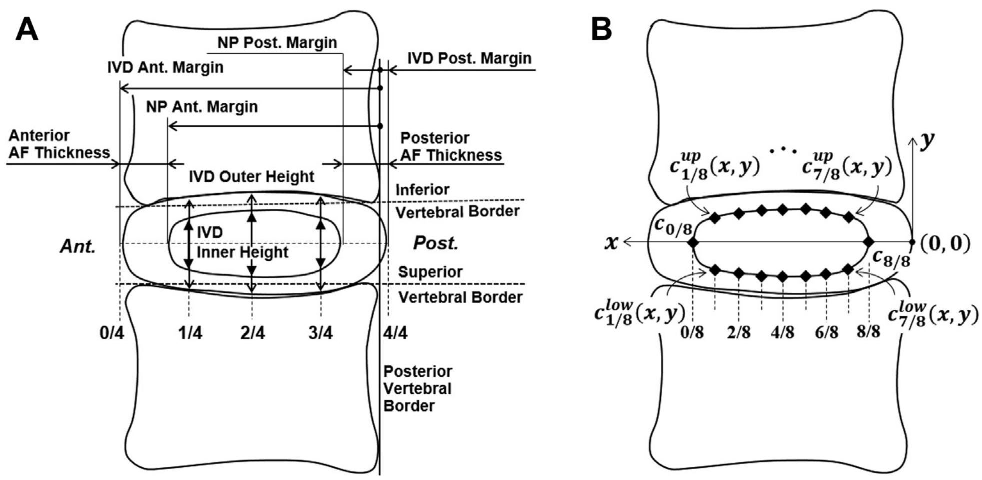

Figure 2. Schematic representation of (A) the parameters for quantifying horizontal positions of intervertebral disk (IVD) and nucleus pulposus (NP), anterior and posterior annulus fibrosus (AF) thicknesses, and IVD outer and inner heights; and (B) the spline interpolation of segmentation points on NP contour for quantifying the morphologic changes of NP on the midline sagittal magnetic resonance image.

eighths (Figure 2B). To compare the NP's relative position within the IVD as well as its sagittal morphology, the 2 contours extracted from the neutral and extension states were plotted on the same x-y plane, where the x-coordinate denoted the distance from the posterior disk margin.

Statistical Analysis

To investigate the statistical significance of the changes between neutral and extension states in all measured parameters, paired *t*-tests were conducted where an alpha value of $P < .05$ was a criterion for accepting the statistically significant differences. Both IVD outer and inner heights, horizontal positions of IVD and NP margins with respect to the vertebral body, and both anterior and posterior AF thicknesses were tested. On the segmented NP contour, x-coordinates of both anterior and posterior NP margins and y-coordinates of all node points also were tested.

To investigate relationships between the segmental extension angle and other parameters, correlation analyses were conducted for the pooled data obtained from all subjects. Spearman correlation coefficients ≥ 0.405 (or ≤ -0.405) [37] and Pearson correlation coefficients ≥ 0.403 (or ≤ -0.403) [37] were considered significant if $P < .01$.

Results

Segmental Extension Angle

The mean segmental extension angle (range of motion between the neutral and extension positions) was $7.9 \pm 3.03°$ at C3-C4, $8.1 \pm 1.73°$ at C4-C5, $3.4 \pm 2.67°$ at C5-C6, and $2.1 \pm 1.73°$ at C6-C7.

Outer and Inner Heights of IVD

As shown in Figure 3, the IVD outer height at the anterior region significantly increased at the upper levels (from 5.77 ± 0.71 mm to 6.45 ± 0.92 mm in C3-C4; from 6.30 ± 0.85 mm to 6.92 ± 0.77 mm in C4-C5; $P < .01$ for both) in extension, whereas no

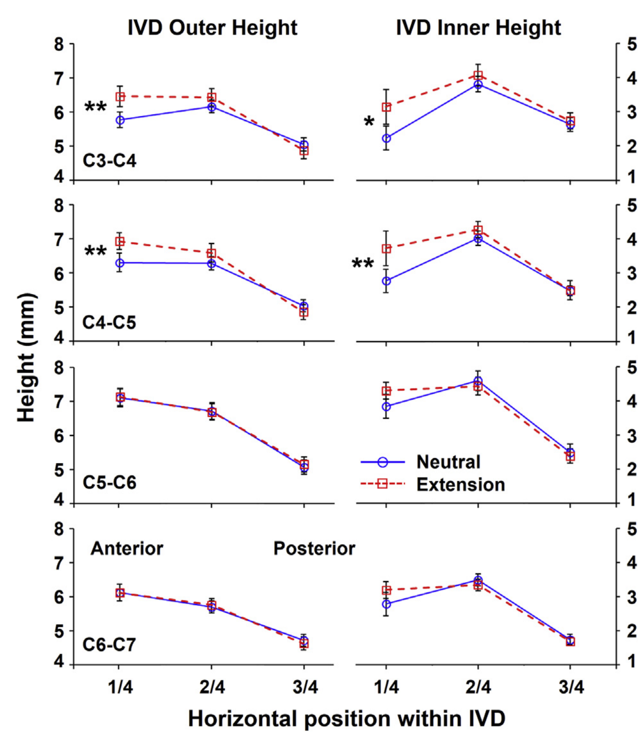

Figure 3. Outer and inner heights of the intervertebral disk (IVD) measured at one-fourth, one-half, and three-fourths of the way between the anterior and posterior disk margins. Standard errors of the means are given; the statistically significant changes between neutral and extension are marked with asterisks (**$P < .01$, *$P < .05$). Note that the y axes ranges differ between the 2 columns.

significant changes were observed at C5-C6 and C6-C7. The inner height also increased at the anterior region in all levels, but the statistical significance was observed only at the upper levels (from 2.24 ± 1.11 mm to 3.15 ± 1.60 mm in C3-C4, $P < .05$; from 2.77 ± 1.09 mm to 3.73 ± 1.60 mm in C4-C5, $P < .01$). At the midpoint, both outer and inner heights slightly increased at C3-C4 and C4-C5 but without significance, whereas those heights at the posterior region showed no changes in any level.

Horizontal Positions of IVD and NP Margins

Figure 4 shows the horizontal positions of both IVD and NP margins with respect to the posterior vertebral border. For the anterior IVD margin, statistically significant change was observed at C3-C4 (from 16.70 ± 1.43 mm to 15.59 ± 1.38 mm, $P < .01$), C4-C5 (from 16.79 ± 1.45 mm to 15.94 ± 0.93 mm, $P < .05$), and C5-C6 (from 17.27 ± 1.44 mm to 16.67 ± 1.39 mm, $P < .01$), when moving from neutral to extension. For the posterior IVD margin, statistically significant change was observed at C3-C4 (from −2.25 ± 0.75 mm to −3.50 ± 0.73 mm, $P < .01$) and C4-C5 (from −2.80 ± 0.82 mm to −3.72 ± 0.58 mm, $P < .01$). Unlike the disk margins, which showed posterior displacement, both NP margins showed no significant changes in their positions relative to the posterior vertebral border in extension compared with the neutral states.

Our data also showed that the anterior AF thickness (the distance between anterior margins of IVD and NP) decreased at C3-C4 (from 4.43 ± 1.02 mm to 3.70 ± 1.19 mm, $P < .05$), C4-C5 (from 3.14 ± 0.75 mm to 2.53 ± 0.75 mm, $P < .05$), C5-C6 (from 3.28 ± 1.12 mm to 2.82 ± 1.54 mm, $P < .01$), and C6-C7 (from 3.34 ± 0.50 mm to 2.87 ± 0.52 mm, $P < .01$). Meanwhile, the posterior AF thickness (the distance between posterior margins of IVD and NP) increased at C3-C4 (from 2.24 ± 0.66 mm to 3.56 ± 0.67 mm, $P < .01$), C4-C5 (from 2.39 ± 1.04 mm to 3.67 ± 1.07 mm, $P < .01$), C5-C6 (from 2.98 ± 1.01 mm to 3.68 ± 0.65 mm, $P < .01$), and C6-C7 (from 3.04 ± 1.07 mm to 3.49 ± 1.09 mm, $P < .05$). Despite the changes in AF thicknesses at both sides, the distance between anterior and posterior IVD margins (horizontal length of IVD) remained unchanged.

Relative Position and Morphology of NP

Figure 5 shows changes in the sagittal morphology of NP and its relative position within the IVD. Both the anterior and posterior NP margins moved forward with respect to the posterior disk margin; statistically significant changes were observed at C3-C4 (from 14.71 ± 1.36 mm to 15.64 ± 1.07 mm, $P < .01$), C4-C5 (from 16.57 ± 1.65 mm to 17.23 ± 1.54 mm, $P < .01$), and C6-C7 (from 16.69 ± 1.90 mm to 17.23 ± 1.79 mm, $P < .05$) for the anterior margin, whereas at C3-C4 (from 2.34 ± 0.89 mm to 3.68 ± 0.89 mm, $P < .01$), C4-C5 (from 2.35 ± 1.02 mm to 3.67 ± 1.08 mm, $P < .01$), and C5-C6 (from 3.09 ± 1.08 mm to 3.72 ± 0.60 mm, $P < .01$) for the posterior margin. At C4-C5, anterior region of the NP thickened (y-coordinates on the upper contour increased from 1.11 ± 0.27 mm to 1.87 ± 0.74 mm at 1/8 location, $P < .01$, from 1.55 ± 0.39 mm to 2.17 ± 0.49 mm at 2/8 location, $P < .01$, and from 1.92 ± 0.41 mm to 2.27 ± 0.55 mm with at 3/8 location $P < .05$), whereas the horizontal length of NP decreased (from 13.83 ± 1.55 mm to 12.92 ± 1.99 mm, $P < .05$) in extension. These noticeable changes in morphology of the NP observed at C4-C5, however, were statistically insignificant at other levels, even though the same trend was observed.

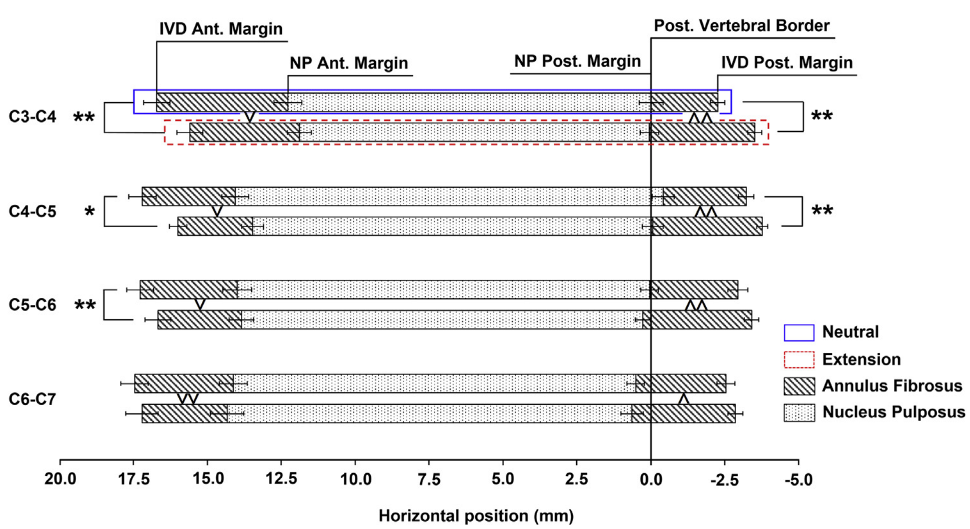

Figure 4. Horizontal positions of the anterior and posterior margins of the nucleus pulposus (NP) and intervertebral disk (IVD) in neutral (upper bar) and extension (lower bar) positions. Whiskers indicate standard errors of the means at both IVD and NP margins. Statistically significant changes in IVD margin positions are marked with asterisks (**$P < .01$, *$P < .05$), while those in AF thicknesses with ∨ or ∧ (2 for $P < .01$ and 1 for $P < .05$), which denote decrease or increase, respectively.

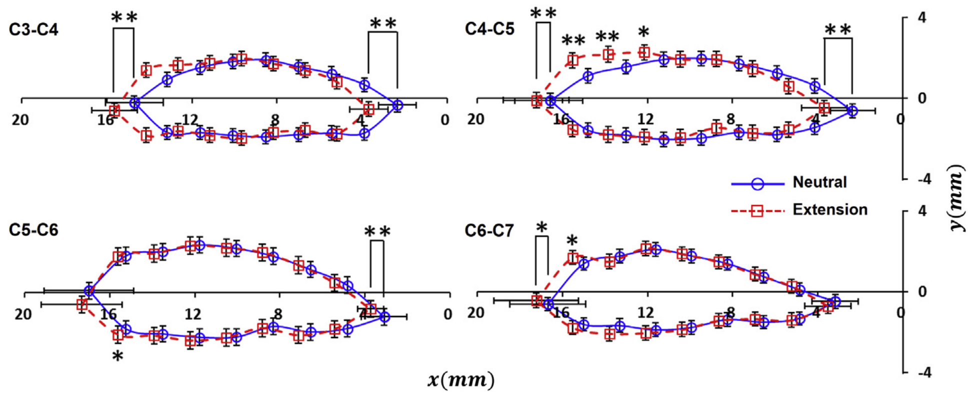

Figure 5. Comparison of horizontal position of nucleus pulposus relative to the posterior disk margin and its sagittal morphology between the neutral (solid line) and extension (dashed line). Error bars indicating the standard deviation for y-coordinates are included on all node points, whereas those for x-coordinates are only on anterior and posterior margins. Statistically significant changes are marked with asterisks (**$P < .01$ and *$P < .05$).

Relationships Between Parameters and Measurements

Table 1 is the correlation coefficient matrix for the pooled data of quantitative parameters and measurements from 10 subjects, which shows Spearman and Pearson correlation coefficients on its lower left and upper right halves, respectively. Not strong but significant positive or negative linear correlations were found between the segmental extension angle and IVD outer height ($r = 0.416$), horizontal distances from the posterior vertebral border to the anterior ($r = -0.420$) and posterior ($r = 0.352$) disk margins, and posterior AF thickness ($r = 0.538$). Weak negative linear correlation was observed between the segmental extension angle and anterior AF thickness ($r = 0.301$). Unlike the other parameters, IVD inner height was not linearly correlated with the segmental extension angle.

Discussion

This study examined the effects of supine cervical extension on deformation of IVD and horizontal positions of IVD and NP margins in asymptomatic subjects. Our data demonstrated that both anterior and posterior IVD margins moved posteriorly with respect to the vertebral body in extension while keeping their distance (horizontal IVD length) unchanged (Figure 4). Both NP

Table 1
Correlation coefficients[†] among the quantitative parameters and measurements

Parameters and Measurements	Segmental Extension Angle	IVD Outer Height[‡]	IVD Inner Height[‡]	Anterior IVD to PVB[§]	Posterior IVD to PVB[§]	Anterior AF Thickness[‖]	Posterior AF Thickness[‖]
Segmental Extension Angle	1.000	0.416** (.008)	0.079 (.628)	−0.420** (.007)	0.352* (.026)	−0.301 (.059)	0.538** (<.001)
IVD Outer Height[‡]	0.423** (.006)	1.000	0.298 (.062)	−0.210 (.193)	0.245 (.128)	−0.006 (.971)	0.210 (.193)
IVD Inner Height[‡]	0.085 (0.600)	0.320* (.044)	1.000	0.010 (.950)	0.057 (.728)	0.099 (.545)	0.189 (.242)
Anterior IVD to PVB[§]	−0.465** (.002)	−0.204 (.208)	0.082 (.617)	1.000	−0.757** (<.001)	0.377* (.016)	−0.495** (.001)
Posterior IVD to PVB[§]	0.303 (.057)	0.214 (.184)	0.209 (.195)	−0.620** (<.001)	1.000	−0.031 (.852)	0.379* (.016)
Anterior AF Thickness[‖]	−0.345* (.029)	0.012 (.944)	0.249 (.121)	0.397* (.011)	−0.018 (.913)	1.000	−0.394* (.012)
Posterior AF Thickness[‖]	0.508** (.001)	0.185 (.253)	0.169 (.297)	−0.450** (.004)	0.308 (.053)	−0.341* (.031)	1.000

IVD = intervertebral disk; PVB = posterior vertebral border; AF = annulus fibrosus; NP = nucleus pulposus.

[†] The Spearman (lower left half) and Pearson (upper right half) correlation coefficients were calculated with data from 40 disks of 10 subjects (n = 40). Spearman correlation coefficients 0.405 (or −0.405) and Pearson correlation coefficients 0.403 (or −0.403) indicate significance of $P < .01$. Significant linear correlations are indicated with asterisks (**$P < .01$, *$P < .05$); P values also are given in parentheses.

[‡] Only the outer and inner heights measured at the anterior region (one-fourth of IVD length from anterior margin of IVD) were included in this correlation analysis, which showed sufficient significance.

[§] Anterior IVD to PVB indicates the horizontal distance between anterior IVD margin and PVB, whereas Posterior IVD to PVB indicates the distance between posterior IVD margin and PVB.

[‖] The decreased anterior AF thickness denotes that the anterior NP margin moved toward the anterior disk margin; the increased posterior AF thickness implies that the posterior NP margin moved away from the posterior disk margin.

margins did not move relative to the vertebral body in extension (Figure 4), whereas they moved anteriorly with respect to the disk margin (Figure 5). The fact that the increment of IVD inner height was greater than that of the outer height at the anterior region (Figure 3) also implies that the NP moved forward within the IVD in extension: the inner height of the anterior IVD increased as the NP was more concentrated toward the anterior region during its anterior migration. This anterior migration of the NP within the IVD might result from the decreased and increased horizontal AF thicknesses (Figure 4) in the anterior and posterior regions, respectively.

To the best of our knowledge, our study is the first to present quantitative data using MRI for relative movement of the NP within the cervical disk according to spinal postures. Only some lumbar studies reported anterior movement of the NP in vivo when moving from flexion to extension by investigating the positional changes of either both NP margins [26,27] or maximal pixel intensity point [28,29] within the IVD. By contrast, Nazari et al [38] claimed that the positional change of NP margins might actually result from NP deformation, rather than the apparent migration reported in other lumbar studies. In our study, however, anterior shift of the NP within the IVD was clearly demonstrated, whereas deformation of the NP was not noticeable except C4-C5 in which the segmental extension angle was greatest (Figure 5). Unlike other lumbar studies [28,29] which showed anterior migration of the NP with respect to the anterior disk margin, Fennell et al [27] reported that the NP moved forward relative to the vertebra. Our results, however, showed that the NP margins moved forward only with respect to the disk margins while remaining in the same positions relative to the vertebral body. We consider this unchanged position of the NP with respect to the vertebra, despite its anterior shift within the IVD, resulted from posterior movement of the disk margins relative to the vertebra, which canceled out anterior migration of the NP relative to the disk margins.

Although it might not be fair to compare our results with the data reported in the lumbar studies, mainly because of the use of different methodologies and/or datum lines for measuring position of the NP, we found that anterior migration of the NP in the cervical IVD was by and large less than that in the lumbar IVD in spinal extension (Table 2). This may be attributed to the morphological features of the cervical disks that are quite different from those of the lumbar disks. According to the description given by Mercer and Jull [31] in their review of the previous studies on the cervical disks, the cervical NP constitutes only about 25% of the entire IVD in volume and is more fibrous, whereas the lumbar NP is more gelatinous, thus more fluidic, and takes nearly half of the disk volume. Although the extent of NP migration in the cervical disks was relatively small compared with the lumbar disks, our observation implies that the NP moving forward within the IVD in cervical extension will reduce stress on the pain-sensitive posterior AF, which might be helpful to alleviate diskogenic neck pain or prevent the annular fissures or tears from being further developed into herniation. However, our results are not sufficient to provide clinical implications about whether the extension maneuver would be conducive to restoring the herniated disks or relieving radicular pain or symptoms caused by the herniated NP in the cervical spine, which needs to be further investigated.

As opposed to the anterior migration revealed in most cases, 5 disks (12.5%) of 4 subjects (1 at C5-C6, 4 at C6-C7) showed paradoxical, posterior movement of the NP relative to the posterior disk margin in extension. Some lumbar studies [27,29] also reported this posterior migration in extension with an occurrence rate ranging from 8.3% to 30%. Edmondston et al [29] stated that

Table 2
Comparison of study results for migration of NP

Source	n	Observation	Datum Line	NP Displacement (%) From Flexion to Extension			
				L1-L2	L2-L3	L3-L4	L4-L5
Brault et al [28] Edmondston et al [29]	10	Peak pixel intensity	Anterior disk margin	10.2 7.6	9.7 6.7	7.8 3.5	6.7 5.7
Source	**n**	**Observation**	**Datum Line**	**NP Displacement (%) From Neutral to Extension**			
				L1-L2	L2-L3	L3-L4	L4-L5
Fennell et al [27]	3	Anterior NP margin Posterior NP margin	Inferior vertebral body	5.8 4.8	7.9 5.1	5.2 6.8	6.7 4.4
Source	**n**	**Observation**	**Datum Line**	**NP Displacement (%) From Neutral to Extension**			
				C3-C4	C4-C5	C5-C6	C6-C7
Current study	10	Anterior NP margin Posterior NP margin	Posterior disk margin	4.8 7.0	3.4 6.9	2.4 3.3	2.4 1.8

The amount of displacement is presented in a normalized form as a percentage of horizontal IVD length, except for the Fennell data, which was normalized by anteroposterior width of inferior vertebra. Positive values represent the anterior migration.
NP = nucleus pulposus; IVD = intervertebral disk.

this paradoxical NP movement might result from disk degeneration referring to Schnebel et al [39], who reported that the degenerative disks behaved more unpredictably than the normal disks. In our data, the posterior NP movement was observed in 14.8% (4 of 27) of mildly degenerative disks, but in 7.7% (1 of 13) of normal disks. Because the number of observations of this paradoxical NP movement (5 of 40) was small, however, we could not find a statistically meaningful relationship between the degeneration; and thus further study is required to draw a firmer conclusion on this.

Posterior movement of the posterior IVD margin means that the posterior AF bulged further in extension, which, interestingly, was observed in 80% (32 of 40) of the total disks examined. Though it cannot be directly compared with our results, Fredericson et al [40], in their lumbar study, reported that the posterior annular bulge increased in flexion but decreased in extension, as opposed to our observation. However, their data were considered statistically not significant because of the small study population ($n = 3$). In other lumbar studies using open MRI, Lee et al [41] and Zou et al [42] reported that the posterior annular bulge decreased in flexion while increased in extension, the latter of which is in line with our observation on the cervical disk. Beattie et al [26] reported that the annular bulge increased in lumbar extension in four of eight subjects with degenerative disks, implying that the additional bulge could be indicative of ongoing degeneration. In our study, however, the increased AF bulge was more frequently observed than they reported: in 74.1% (20 of 27) of mildly degenerative disks and 92.3% (12 of 13) of normal disks. Therefore, we believe that this additional bulge is more likely to be observed in normal disks rather than the degenerative ones.

We interpret the posterior annular bulge in extension as part of the natural consequences of deformation of the IVD, based on the Poisson effect commonly seen in the deformable materials: posterior AF expanded horizontally (horizontal thickness of posterior AF increased) as it was compressed vertically by the angulation of vertebral bodies, which caused the posterior disk margin to bulge further backwards. The more noticeable AF bulge in the cervical disks, which was not markedly observed in the lumbar studies [26-30,38], may be attributed to the greater disk compliance [43,44] and intersegmental angle of the cervical motion segment. It is believed that the greater bending compliance of the cervical disks, presumably due to their distinctive chemical morphology, allows greater deformation of the IVD and thus greater range of spinal motion when compared with the lumbar spine [34]. It is thought that the increased annular bulge in cervical extension may contribute to the decrease of neuroforaminal size [45-48] and increase of intraforaminal pressure [49] reported in the literature, secondary to the narrowing of bony space within the foramen, given that the anterior boundary of the neural foramen is formed by posterolateral margin of the IVD [48]. Therefore, our observation may offer part of the reason for unilateral pain exacerbation in patients with disk herniation involving radicular symptoms, which accounts for 20% to 25% of cases [21,22] among the various pathoanatomical features contributing to cervical radiculopathy [9,13]; however, because of the remaining uncertainty about whether the extended position of the cervical spine would help retract the herniated NP or worsen the nerve root compression, further investigation should be conducted towards the clinical relevance of applying the extension maneuver to the patients with cervical disk herniation.

Given that most of the parameters were significantly correlated with the segmental extension angle (Table 1), we could infer that the angulation of vertebrae might be a major mechanical alteration that resulted in those changes. Most of the changes were relatively less significant in C5-C6 and C6-C7, where the extension angles were smaller than the upper disk levels. Further study is needed to see if the greater extension angles and more significant changes can be seen in the lower levels during the upright or active extension.

Limitations of This Study

A few limitations of this study should be considered. First, the number of subjects was limited; further research with a larger study population is necessary for more conclusive evidence. Second, this study was conducted on male subjects and therefore gender differences may not be realized. Next, the imaging was performed in supine participants, whereas most of the clinical testing, such as Spurling test [50] and extension test [51], is conducted in upright individuals who will have additional loads acting upon the cervical spine, and thus the influence of different intradiskal pressures between supine and upright positions has not been addressed in this study. Also, the intradiskal changes were evaluated from the passively extended cervical spine, and thus the impact of muscle activities or different spinal configurations in active extension has not been quantified. Therefore, further study is required to investigate whether the same results would be applicable to the active/passive extension while sitting or standing. Last, all implications of this study are based upon the results obtained from young, healthy subjects; therefore, caution should be exercised when applying our results to the pathologic conditions, and further investigation is required.

Conclusion

In extension, the NP moved forward relative to the disk margin and the posterior AF bulged further backwards with increased horizontal thickness. Our findings suggest that the cervical extension maneuver, which induces the anterior migration of NP away from the posterior disk margin, may have a clinical effect on cervical diskogenic pain resulting from internal disk disruption. However, further research is needed to demonstrate the clinical impact or relevance of cervical extension on the herniated disks and associated radicular symptoms.

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CME Question

The nucleus pulposus of cervical disks:

a. Constitutes approximately 25% of the intervertebral disk.
b. Has more relative fluid volume of the disk than the lumbar disks.
c. Is more gelatinous than the nucleus pulposus of lumbar disks.
d. Has more anterior migration with extension compared to the lumbar disks.

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