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The Response of the Nucleus Pulposus of the Lumbar Intervertebral Discs to Functionally Loaded Positions

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Study Design. Asymptomatic volunteers underwent magnetic resonance imaging to investigate how different positions affect lumbar intervertebral discs.

Objective. To quantify sagittal migration of the lumbar nucleus pulposus in 6 functional positions.

Summary of Background Data. Previous studies of the intervertebral disc response in the sagittal plane were limited to imaging of recumbent positions. Developments of upright magnetic resonance imaging permit investigation of functional weight-bearing positions.

Methods. T2-weighted sagittal scans of the L1–L2 to L5–S1 discs were taken of 11 volunteers in standing, sitting (upright, flexed, and in extension), supine, and prone extension. Sagittal migration of the nucleus pulposus was measured (mm) as distance from anterior disc boundary to peak pixel intensity. Lumbar lordosis (Cobb angle) was measured in each position.

Results. Fifteen comparisons between positions showed significant positional effects (14 at L4–L5, L5–S1, the most mobile segments). Prone extension and supine lying induced significantly less posterior migration than sitting. Flexed and upright sitting, significantly more than standing at L4–L5, as did flexed sitting compared with extended.

Conclusion. These results support for the first time the validity of clinical assumptions about disc behavior in functional positions: sitting postures may increase risk of posterior derangement, and prone and supine may be therapeutic for symptoms caused by posterior disc displacement.

Key words: upright MRI, nucleus pulposus, intervertebral disc, functional positions. **Spine 2007;32:1508–1512**

Intervertebral disc (IVD) problems, principally excessive migration of the nucleus pulposus (NP) and disruption of the anulus fibrosus (AF), are generally accepted to be one of the main causes of nonspecific back pain.[1–4] Around 40% of people with low back pain are thought to have pain of discogenic origin.[5,6] The apocryphal "slipped disc," disc bulging or ultimately prolapse leading to impingement, is a major cause of work absence in industrialized societies.[7] The assumption that (primarily) extension and flexion cause, predictable and repeatable, anterior and posterior (respectively), migrations of the NP underlies popular conservative therapeutic interventions, such as the McKenzie regimen,[8] where exercises and postural corrections, designed to reduce such migrations and resultant impingement, are prescribed. While some *in vivo* work is available, the evidence base for such treatments is extremely limited as *in vitro* study of the response of IVD to everyday postures, such as sitting, standing, and bending, has not previously been reported. Magnetic resonance imaging (MRI), which allows visualization of IVDs, has hitherto been restricted due to imaging of cadavers,[9,10] or nonfunctional recumbent positions, which remove the effects of both gravity and forces generated by functional muscle work due to scanner design.[11–14] Moreover, the limited space permitted in the completely enclosed scanners used, due to magnet bore, has been noted to limit subject's movements.[12]

Beattie *et al*[13] examined supported supine flexion and extension (lying on a lumbar roll) in 20 normal female subjects. They reported the distance from the posterior boundary of the NP, to the posterior boundary of the AF, decreased significantly in extension (*vs.* flexion) at L3–L4, L4–L5, and L5–S1 levels. While there was also a reduction trend in the anterior distances, this was not significant, suggesting perhaps an anterior compression of the NP, in extension, but no significant migration. Fennell *et al*[12] examined neutral, extended, and flexed side lying, in 3 normal subjects and found a similar pattern. Brault *et al* investigated the issue through measurement of "peak pixel intensity," which occurs at the center of the NP representing the peak area of hydration within the disc.[14] They reported significantly greater anterior migration in extended compared with flexed, supported supine lying, at L1–L2, L2–L3, and L3–L4 levels. Edmondston *et al*[11] used the same technique and positions, with 10 asymptomatic volunteers, reporting a significant anterior migration at L1–L2, L2–L3, and L5–S1 in supported supine extension.

With the development of upright positional MRI (pMRI) scanners, it is possible to image the spine in both upright/functional and recumbent positions, the great diagnostic advantage being imaging of the spine in the load-bearing postures which trigger symptoms.[15–17] Initial work by Jinkins and Dworkin[16] has documented pMRI scanning of subjects with degenerative spinal conditions sitting in normal, flexed, and extended positions and supine. They reported pronounced differences between loaded and unloaded positions and that pathology

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Figure 1. Examples of scanning position used: extended sitting, standing, flexed sitting and prone extension.

such as dysfunctional intersegmental motion was revealed only under axial loading.[16] The present study investigated the response of the NPs, of the lumbar IVDs of normal subjects in 6 different functional positions: standing (referred to as P1), sitting (upright, P2; flexed, P3; and in extension, P4), supine (P5), and prone extension (P6).

■ Materials and Methods

A convenience sample of 11 healthy volunteers was recruited by response to a general notice and word of mouth. Approval was obtained from both Grampian NHS and Robert Gordon University ethics committees, and all subjects gave informed written consent before their participation in this project. Subjects were included if they had no present back pain and no history of requiring treatment for back pain, no cognitive, mental, or communication impairment preventing informed consent, and age between 18 and 60 years. Subjects were excluded from the study if they had any contraindications to an MRI procedure or shoulder/hip width greater than 45 cm (width of pMRI).

A 0.6 Tesla, positional "Upright" MRI (Fonar Corp., Melville, NY) was used to carry out the scans. This scanner can image in supine, erect (weight-bearing), and seated positions in both neutral and other (*e.g.*, flexed/extended) postures.[15,18] Sagittal (TR-3848, TE-120) weighted images through the 5 lumbar IVDs were taken: field of view = 30 cm, slice thickness = 4.5 mm, slice interval = 5 mm, acquisition matrix = $180 \times 256/3$NEX, imaging time = 4 to 5 minutes per sequence. The same radiographer carried out each scan at the same time each day (to minimize diurnal effects[19]), in the same order: standing, sitting (upright, flexed, and in extension), supine, and prone extension (Figure 1). Initial pilot work revealed that this sequence minimized subject discomfort. Sitting in extension and prone extension were maintained passively using foam rolls and wedges. Subjects were required to maintain each position for approximately 10 minutes per scan.

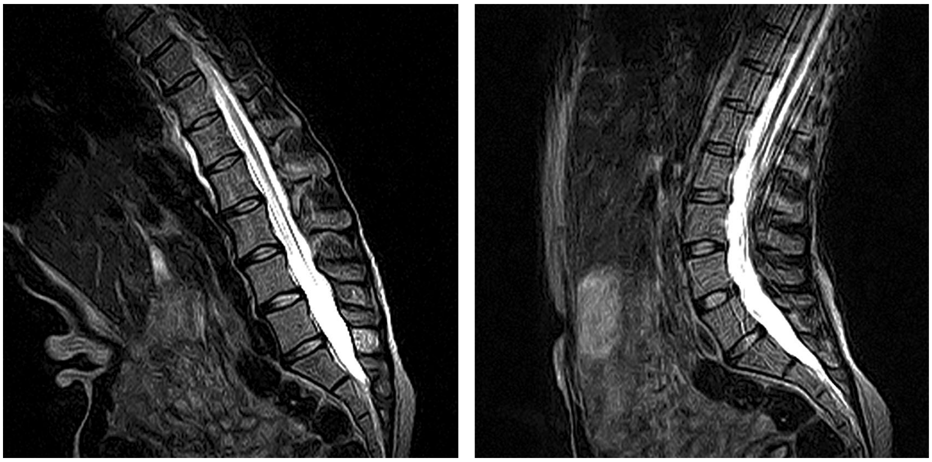

Figure 2. Example mid-sagittal slice scans of a subject in extended and flexed sitting.

All images were transferred to CD ROM, and subsequent measurements were taken with the Osiris 4.19 software program (University of Geneva, Geneva, Switzerland) by the same researcher. In addition, all images were examined and reported by a consultant radiologist (Figure 2, examples of scan images).

The midsagittal slice image was identified for each subject, in each position. To examine if the different positions affected the extent of lumbar lordosis, the Cobb angle (the angle between the superior vertebral endplates of L1 and S1) for each posture was measured.[20] The same researcher then located the center of the NP in each image using the peak pixel intensity method of Brault *et al.*[14] This is where the mid-disc line and the point of peak pixel intensity on that line are identified. The distance from the anterior disc boundary to this point was then recorded in millimeters and defined as the extent of sagittal migration of the NP; therefore, greater values represented greater posterior migration. Before analyzing the effect of position on NP migration, the intraoperator reliability of locating the NP center was assessed by measuring each midsagittal scan, for each subject, at each level and each position, 3 times on a blind basis.

Separate intraclass correlation coefficients (ICCs), for each level, in each position, were calculated to quantify the intraoperator reliability of location of the NP center. Before inferential testing, normality of distribution was examined with the Shapiro-Wilk test. Where distribution was not within acceptable limits of normality ($P < 0.05$), nonparametric models were applied. To determine the effect of the 6 positions measured on lumbar lordosis, differences between the Cobb angles in each position were tested with repeated measures ANOVA. Where significant effects were found, *post hoc* testing (paired *t* tests) of all possible comparisons was applied. With Bonferroni correction (15 tests), statistical significance was determined at $P < 0.003$.

The effect of the positions on the sagittal migration of each of the NPs was investigated using separate Friedman's tests for the NPs at L1–L2 and L2–L3 (NP1 and NP2, respectively) and separate repeated-measures analysis of variance (ANOVA) for the NPs at L3–L4, L4–L5, and L5–S1 (NP3, NP4, and NP5, respectively). Statistical significance was determined at $P < 0.05$. Where significant effects were found, *post hoc* testing (Wilcoxon for Friedman's tests and paired *t* tests for ANOVAs) of all possible comparisons between positions, at each NP, were applied. With Bonferroni correction (15 tests), statistical significance was determined at $P < 0.003$.

Results

Seven females and 4 males completed the study: all except one were employed; age (mean ± SD), 36 ± 9 years; height 1.72 ± 0.08 m; and weight, 72.09 ± 14.25 kg.

A high level of intratester reliability was found for the NP translation measurements (performed with the OSIRIS 4.19 software program) with ICC for each position ranging from 0.71 to 0.97 (mean ± SD, 0.89 ± 0.06). While the consultant radiologist did identify degenerative changes in 6 subjects, these were indicative of normal, age-appropriate "wear and tear" in a healthy spine. The mean Cobb angles for sitting positions were as follows: P3, flexed 1.6° (±7.2°), P2, upright 21.5° (±10.1°), and P4, extended 50.2° (±8.1°) with, P5, supine lying 51.4° (±6.4°), P1, standing 52.8° (±12.9°), and P6, prone extension 61.4° (±7.1°). Significant differences were found (ANOVA), and *post hoc* testing indicated that upright and flexed sitting were significantly lower (less lordosis) than every other position ($P < 0.001$) and prone extension significantly greater (increased lordosis) than every other position except standing ($P < 0.001$). While not significantly different between every successive step, this rank order supports the anticipated effect of these functional positions on lumbar lordosis.

The ANOVA and Friedman's analysis revealed that at all levels position exerted a statistically significant influence on the sagittal migration of the NP. To determine between which positions the significant differences lay, *post hoc* analysis was performed, and the results are presented in Table 1.

The NPs of the lowest IVD levels, NP4 and NP5 (IVDs L4–L5 and L5–S1, respectively), were the most affected by position, in that every position was significantly different from at least one other. Fifteen significant differences were found: 11 from comparison of loaded and unloaded and 4 from unloaded positions. The magnitude and direction of the significant differences between loaded positions are presented in Table 2.

Table 1. Results of Pairwise Post Hoc Comparisons of the Effect of Six Different Positions on the Posterior Migration (mm) of Individual Nucleus Pulposus of the Lumbar Vertebrae

	P2	P3	P4	P5	P6
P1	NP4, NP5	NP4			
P2				NP4, NP5	NP3, NP4, NP5
P3			NP4	NP4, NP5	NP4, NP5
P4				NP5	NP5

P1 indicates standing; P2, upright sitting; P3, flexed sitting; P4, sitting in extension; P5, Supine; P6, prone extension; NP3, significant difference between positions ($P < 0.003$) for nucleus pulposus 3; NP4, significant difference between positions ($P < 0.003$) for nucleus pulposus 4; NP5, significant difference between positions ($P < 0.003$) for nucleus pulposus 5.

Both upright and flexed sitting induced significantly more posterior migration of NP4 than did standing, with the same effect observed for upright sitting at NP5. The magnitude and direction of the significant differences in NP sagittal migration, from the comparisons between loaded and unloaded positions, are presented in Table 3.

Discussion

The aim of this study was to investigate the NP response to different functional positions in normal subjects. While it is difficult to guarantee a sample with completely normal spines, the present sample did meet specific inclusion criteria and all scans were classified as within normal limits by a consultant radiologist.

Previous authors[12,13] visually identified both anterior IVD margin and NP boundary but did not report ICCs. Peak pixel intensity was used in this study to identify the NP center. This yielded a mean ICC of 0.89; Edmondston *et al* reported 0.71 with the same technique.[11] This more objective technique may yet yield greater benefits when scanning degenerative discs where visual identification of boundaries may be even more difficult.

Initial analysis showed that the NPs of the lowest IVD levels, NP4 and NP5 (IVDs L4–L5 and L5–S1, respectively), displayed the greatest differences in sagittal migration between position: 14 of the 15 significant differences found occurred at NP4 and NP5. This finding accords with the theoretical model of posterior migration, leading to disc bulging and ultimately pathology, in that previous studies report that most disc derangements occur at the most mobile motion segment, L4–L5.[21,22] Previous MRI studies investigating the response of the NP to flexion and extension found that anterior migration was most apparent in the upper 4 lumbar discs, but this was in unloaded and nonfunctional, recumbent positions.[11,12] The present results differ in that NP migration was different in these loaded, functional, positions. This accords with the generally accepted clinical finding of disc derangement at lower levels in that no significant differences in posterior migration were found at higher (L1–L2, L2–L3) levels; and at NP3 (L3–L4), only the difference between prone extension and upright sitting was significant.

Table 2. Mean Difference (mm, 95% CI, and % of Anteroposterior Disc Width) and Direction of the Statistically Significant Differences in the Posterior Migration of Individual Nucleus Pulposus of the Lumbar Vertebrae From the Comparisons Between Loaded Positions

	P2 > P1	P3 > P1	P3 > P4
NP4	5.7 2.6–8.9 17.8%	6.1 2.6–9.7 19.1%	5.1 2.5–7.7 15.9%
NP5	6.9 3.2–10.6 22.1%	NS	NS

> indicates significantly greater posterior migration than; NP4, nucleus pulposus 4; NP5, nucleus pulposus 5; P1, standing; P2, upright sitting; P3, flexed sitting; P4, sitting in extension; NS, not significant.

Table 3. Mean Difference (mm, 95% CI, and % of Anteroposterior Disc Width) and Direction of the Statistically Significant Differences in the Posterior Migration of Individual Nucleus Pulposus of the Lumbar Vertebrae From the Comparisons Between Loaded (Standing, Upright, Flexed, and Extended Sitting) and Unloaded (Supine and Prone Extension) Positions

	P2 > P6	P3 > P6	P4 > P6	P2 > P5	P3 > P5	P4 > P5
NP3	4.7 2.9–6.4 14.9%					
NP4	6.3 4.6–8.1 19.7%	6.7 3.4–10.1 20.9%		5.2 3.2–7.3 16.3%	5.6 2.5–8.8 17.5%	
NP5	8.7 5.8–11.5 27.9%	6.3 2.9–9.7 20.2%	6.4 3.0–9.8 20.5%	9.5 6.3–12.6 30.5%	7.1 3.3–10.9 22.8%	7.2 3.6–10.9 23.1%

> indicates significantly greater posterior migration than; NP3, nucleus pulposus 3; NP4, nucleus pulposus 4; NP5, nucleus pulposus 5; P1, standing; P2, upright sitting; P3, flexed sitting; P4, sitting in extension; P5, supine; P6, prone extension.

In the comparisons of loaded positions both P2, upright and P3, flexed sitting induced significantly more posterior migration of NP4 than did P1, standing; with the same effect observed for upright sitting at NP5. Flexed sitting also induced significantly more posterior migration than sitting in extension at NP4. This suggests that standing may well be preferable, in terms of reduced risk of posterior derangement than the classically "poor" sitting postures: upright and flexed. Interestingly, sitting in extension, which is generally accepted as a "better" sitting posture, did not differ significantly from standing, which would suggest that, for normal subjects, both standing and sitting in extension are preferable. Flexed sitting induced significantly greater posterior migration of NP4 than sitting in extension. This latter finding, in conjunction with the Cobb angle analysis, which verified that the positions tested had the expected effects on lumbar lordosis, supports the hypothesis that maintenance of the lumbar lordosis, when sitting, should reduce the risk of posterior disc derangement, at the most commonly affected level, L4–L5.[21]

The results from the comparisons of the loaded and unloaded positions also revealed the pattern of significant positional effect at NP4 and NP5 (with only 1 exception, upright sitting being greater than prone extension at NP3) discussed earlier. Prone extension, a posture commonly used as a treatment technique in physical therapies,[8] induced significantly less posterior migration than any of the 3 sitting positions. Interestingly, supine lying also showed significantly less posterior migration than any of the 3 sitting positions at the same levels. Moreover, there was no appreciable pattern of difference in the levels of mean difference or the 95% confidence intervals in the significant comparisons of sitting to prone extension and supine. This finding may suggest support for the hypothesis that this popular therapeutic technique may in fact be no better than simply lying down in terms of posterior disc derangement. This apparent lack of support for this popular treatment may have reflected the fact that, due to the scanning technique, prone extension (and all other positions measured) was maintained for approximately 5 minutes, as opposed to active, full range repeated but not sustained prone extension, which is used as a therapeutic exercise. In contrast, the Cobb angle analysis revealed that prone extension induced greater mean lordosis (61.4°) than did supine (51.4°). While this difference was nonsignificant, it does at least support the assertion that greater lordosis did occur but perhaps not end of range. Until such time as real-time active scanning is possible, this limitation is unavoidable.

■ Key Points

- To our knowledge, this is the first study of sagittal migration of nucleus pulposus in functional positions.
- We used upright MRI to see the effect of different functional positions on the nucleus pulposus.
- Our results support previously reported theories and models of disc behavior.

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