Title:

The response of the Nucleus Pulposus of the Lumbar Intervertebral discs to functionally loaded positions.

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Abstract

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

Objective: To quantify sagittal migration of the lumbar nucleus pulposus in six 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 positional magnetic resonance imaging permit investigation of functional weight-bearing positions.

Methods: T2 weighted, sagittal scans of the L1/2 to L5/S1 discs were taken of eleven volunteers in Standing, Upright, Flexed and Extended sitting, 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 in each position was measured using Cobb angle.

Results: 15 comparisons between positions showed significant positional effects. 14 at L4/5, 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 L4/5, as did Flexed sitting compared to Extended.

Conclusion: These results support for the first time the validity of several clinical assumptions about disc behavior in functional positions. The result support the assertion that sitting postures may increase risk of posterior derangement and Prone and Supine lying may be therapeutic.

Key Words:

Positional MRI, nucleus pulposus, intervertebral disc, functional positions

Key Points

- To our knowledge the first study of sagittal migration of nucleus pulposus in functional positions
- Use of positional MRI
- Support previous theories and models of disc behavior

Mini Abstract/Précis

3 sentences < 50 words

Positional MRI of functional positions demonstrated significant effects at L4/5, L5/S1 in 14 of 15 significant comparisons. Prone and Supine lying less posterior migration than sitting; extended sitting less than flexed. This supports assumed disc behaviors - sitting may increase risk of posterior derangement, Prone and Supine may be therapeutic.

Introduction

Intervertebral disc (IVD) problems - principally excessive migration of the Nucleus Pulposus (N) and disruption of the Annulus Fibrosis (AF) - are generally accepted to be one of the main causes of non-specific back pain (Sehgal & Fortin 2000; Wetzel and Donalson, 2003; Biyani and Andersson, 2004; Hurri & Karppinen 2004). Around 40% of people suffering from low back pain are thought to be of discogenic origin (Schwarzer et al 1995; Hammer 2002). The apocryphal, 'slipped disc' - disc bulging or ultimately prolapse leading to impingement - is a major cause of work absence in industrialised societies (Andersson, 1999). The assumption that (primarily) extension and flexion cause, predictable and repeatable, anterior and posterior (respectively), migrations of the N underlies popular conservative therapeutic interventions, such as the McKenzie regime (McKenzie 1989); where, exercises and postural corrections, designed to reduce such migrations and resultant impingement, are prescribed. The evidence base for such treatments is extremely limited, however, as there is no literature on the IVD's response to everyday postures such as sitting, standing and bending. Magnetic Resonance Imaging (MRI), which allows visualisation of IVDs, has hitherto been restricted to imaging of cadavers (Krag, et al, 1987, Seroussi et al, 1989) or non-functional recumbent positions which remove the effects of both gravity and forces generated by functional muscle work due to scanner design (Edmondston et al, 2000; Fennell et al, 1996; Beattie et al, 1994; Brault et al, 1997). Moreover, the limited space permitted in the completely enclosed scanners used, due to magnet bore, has been noted to limit subject's movements (Fennell et al 1996).

Beattie et al (1994) 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 N, to the posterior boundary of the AF, decreased significantly in extension (compared to flexion) at L 3/4, 4/5 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 N, in extension, but no significant migration. Fennell et al (1996) examined neutral, extended and flexed side lying, in three normal subjects and found a similar pattern. Brault et al (1997) investigated the issue through measurement of, 'peak pixel intensity', which occurs at the centre of the N representing the peak area of hydration within the disc. They reported significantly greater anterior migration, in extended compared to flexed, supported supine lying, at L1/2, 2/3 and 3/4 levels. Edmondston and colleagues (2000) used the same technique and positions, with ten asymptomatic volunteers - reporting a significant anterior migration at L1/2, 2/3 and L5/S1 in supported supine extension.

With the recent advent of Positional MRI (pMRI) scanners, for the first time, it is possible to view both upright/functional and recumbent positions; the great diagnostic advantage being imaging of the spine in the load bearing postures which trigger symptoms (Smith & Pope, 2003; Jinkins & Dworkin, 2002; Siddiqui et al 2005). Initial work by Jinkins & Dworkin (2002) has documented pMRI scanning of subjects with degenerative spinal conditions in normal, flexed and extended sitting and supine. They reported pronounced differences between loaded and unloaded positions and that pathology such as dysfunctional inter-segmental motion were revealed only under axial loading (Jinkins & Dworkin, 2002). The present study investigated the response of the Ns, of the lumbar IVDs of normal subjects in six different functional positions:

standing; upright, flexed & extended sitting; supine and prone extension.

Materials and Methods

A convenience sample of 11 healthy volunteers (7 females, 4 males: mean age 36 years, standard deviation 9) 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 prior to 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 aged between 18-60 years. Subjects were excluded from the study if they had any contraindications to a MRI procedure or shoulder/hip width greater than 45cm (width of pMRI).

A 0.6 Tesla, positional MRI (Fonar "Upright", Fonar Corp., Melville, NY) was employed 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 (Harvey et al 1998, Smith & Pope 2003). Sagittal (TR-3848, TE-120) weighted images through the five lumbar intervertebral discs were taken - field of view = 30cm, slice thickness = 4.5mm, slice interval = 5mm, acquisition matrix = 180x256/3NEX, imaging time = 4-5 min per sequence. The same radiographer carried out each scan at the same time each day (to minimise diurnal effects, Bashir et al 2003), in the same order: standing, upright, flexed, extended sitting, supine and prone extension (see figure 1) – initial pilot work revealed that this sequence minimised subject discomfort. Extended sitting and prone extension were maintained using foam rolls and wedges. Subjects were required to maintain each position for approximately 10 minutes per scan.

Insert figure 1 about here

All images were transferred to CD ROM and subsequent measurements were taken with the Osiris 4.19 software programme (University of Geneva, Switzerland) by the same researcher. In addition, all images were examined and reported by a Consultant Radiologist (see figure 2 for examples of scan images).

Insert figure 2 about here

The mid-sagittal 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 (Shea et al 1998). The same researcher then located the centre of the N in each image using the peak pixel intensity method of Brault et al (1997). 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 mm and defined as the extent of sagittal migration of the N - therefore greater values represented greater posterior migration. Prior to analysing the effect of position on N migration the intra-operator reliability of locating the N centre was assessed by measuring each mid-sagittal scan, for each subject, at each level and each position, three times.

Separate intra-class correlation coefficients (ICC), for each level, in each position, were calculated to quantify the intra-operator reliability of location of the N centre.

Prior to inferential testing normality of distribution was examined with the Shapiro-Wilk test. Where distribution was not within acceptable limits of normality ($p<0.05$) non-parametric models were applied. To determine the effect of the six 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 Ns was investigated using; separate Friedman's tests for the Ns at L1/2 and L2/3 (N1 and 2 respectively) and separate repeated measures ANOVAs for the Ns at L3/4, L4/5 and L5/S1 (Ns 3, 4 and 5 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 N, were applied. With Bonferroni correction (15 tests) statistical significance was determined at $p<0.003$.

Results

A high level of intra-tester reliability was found for the N translation measurements (performed with the OSIRIS 4.19 software programme) with intra-class correlations (ICC) for each position ranging from 0.706 to 0.973, (mean 0.894, SD +/- 0.061). While the Consultant Radiologist did identify degenerative changes in six subjects these were indicative of normal, age appropriate 'wear and tear' in a healthy spine. The mean Cobb angles for sitting positions were - P3, flexed 1.65° (+/- 7.23°), P2, upright 21.49° (+/- 10.08°) and P4, extended 50.21° (+/- 8.14°) with, P5, supine lying 51.43° (+/- 6.37°), P1, standing 52.76° (+/- 12.89°) and P6, prone extension 61.37° (+/- 7.01°). 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 N. To determine between which positions the significant differences lay, post-hoc analysis was performed and the results are presented in Table 1.

Insert Table 1 about here

The N's of the lowest IVD levels, Ns 4 and 5 (IVDs L4/5 and L5/S1 respectively) were the most affected by position; in that every position was significantly different from at least one other. 15 significant differences were found; 11 from comparison of loaded and unloaded and four from unloaded, positions. The magnitude and direction of the significant differences between loaded positions are presented in Table 2.

Insert Table 2 about here

Both Upright and Flexed sitting induced significantly more posterior migration of N 4 than did Standing; with the same effect observed for Upright sitting at N5. The magnitude and direction of the significant differences in N sagittal migration, from the comparisons between loaded and unloaded positions, are presented in Table 3.

Insert Table 3 about here

Discussion

The aim of this study was to investigate the N response to different functional positions. Previous authors (Fennel et al, 1996 and Beattie et al, 1994) visually identified both anterior IVD margin and N boundary but did not report ICCs. Peak pixel intensity was employed in this study to identify the N centre. This yielded a mean ICC of 0.894 - Edmondston et al, 2000 reported 0.71 with the same technique. 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 N's of the lowest IVD levels, Ns 4 and 5 (IVDs L4/5 and L5/S1 respectively) displayed the greatest differences in sagittal migration between position - 14 out of the 15 significant differences found occurred at N 4 and 5. 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, L4/5 (Knop-Jergas et al, 1996, Kanayama et al 1996). While previous MRI studies investigating the response of the N to flexion and extension found anterior migration was most apparent in the upper four lumbar discs, crucially however, this was in unloaded and non functional, recumbent positions (Edmondston, 2000 and Fennel, 1996). The present results differ in that N 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 (L1/2, 2/3) levels and at N3 (L3/4) only the difference between prone extension and upright sitting was significant.

In the comparisons of loaded positions both P2, upright and P3, flexed sitting induced significantly more posterior migration of N 4 than did P1, Standing; with the same effect observed for upright sitting at N5. Flexed sitting also induced significantly more posterior migration than extended sitting at N4. 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, Extended sitting, 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 extended sitting are preferable. Flexed sitting induced significantly greater posterior migration of N4 than Extended sitting. 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, L4/5 (Knop-Jergas et al, 1996).

The results from the comparisons of the loaded and unloaded positions also revealed the pattern of significant positional effect at N 4 and 5 (with only one exception, Upright sitting being greater than prone extension at N3) discussed earlier. Prone extension, a posture commonly employed as a treatment technique in Physical Therapies (such as the McKenzie regime, McKenzie, 1989), induced significantly less posterior migration than any of the three sitting postions. Supine lying, however, also showed significantly less posterior migration, in the same comparisons, at the same levels. Moreover, there was no appreciable pattern of difference in the levels of mean difference or the 95% CI's 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 five 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 (61.37°) than did Supine at (51.43°). While this difference was non significant it does at least support he 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.

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Table 1: Results of pair-wise post-hoc comparisons of the effect of six different positions - Standing, Upright sitting, Flexed sitting, Extended sitting, Supine and Prone Extension - 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 = Standing, P2 = Upright sitting, P3 = Flexed sitting, P4 = Extended sitting, 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

Table 2: Mean difference (mm, 95% CI and % of antero-posterior 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 - Standing, Upright, Flexed and Extended sitting

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

> = Significantly greater posterior migration than

NP4 = Nucleus Pulposus 4, NP5 = Nucleus Pulposus 5

P1 = Standing, P2 = Upright sitting, P3 = Flexed sitting, P4 = Extended sitting

NS = Not significant

Table 3: Mean difference (mm, 95% CI and % of antero-posterior 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	6.7		5.2	5.6	
	4.6-8.1	3.4-10.1		3.2-7.3	2.5-8.8	
	19.7%	20.9%		16.3%	17.5%	
NP5	8.7	6.3	6.4	9.5	7.1	7.2
	5.8-11.5	2.9-9.7	3.0-9.8	6.3-12.6	3.3-10.9	3.6-10.9
	27.9%	20.2%	20.5%	30.5%	22.8%	23.1%

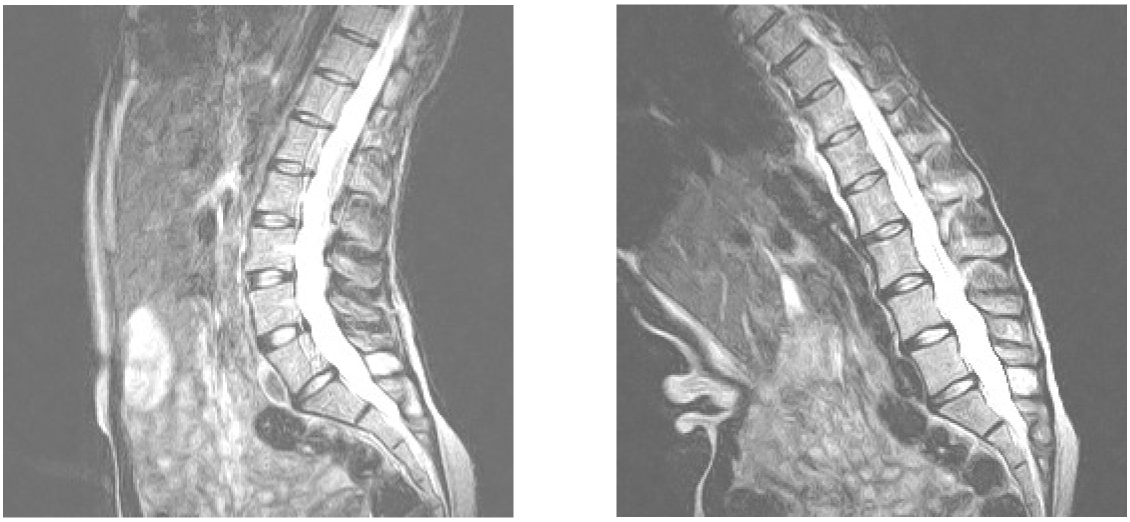
> = Significantly greater posterior migration than

NP3 = Nucleus Pulposus 3, NP4 = Nucleus Pulposus 4, NP5 = Nucleus Pulposus 5

P1 = Standing, P2 = Upright sitting, P3 = Flexed sitting, P4 = Extended sitting, P5 = Supine, P6 = Prone Extension

Figure 1. Scanning positions employed; Standing, Upright sitting, Flexed sitting, Extended sitting, Supine and Prone Extension

Figure 2: Example mid-sagittal slice scans of a subject in Extended and Flexed sitting



Extended Flexed