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The Spine Journal 8 (2008) 982–990

THE SPINE JOURNAL

Technical Reviews

Stress in lumbar intervertebral discs during distraction: a cadaveric study

Ralph E. Gay, MD, DC[a,b,*], Brice Ilharreborde, MD[b], Kristin D. Zhao, MS[b], Lawrence J. Berglund, BS[b], Gert Bronfort, DC, PhD[c], Kai-Nan An, PhD[b]

[a]*Department of Physical Medicine and Rehabilitation, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA*

[b]*Biomechanics Laboratory, Division of Orthopedic Research, Mayo Clinic, 200 1st St. SW, Rochester, MN 55905, USA*

[c]*Northwestern Health Sciences University, 2501 W 84th St., Bloomington, MN 55431, USA*

Received 12 December 2006; accepted 31 July 2007

Abstract

BACKGROUND CONTEXT: The intervertebral disc is a common source of low back pain (LBP). Prospective studies suggest that treatments that intermittently distract the disc might be beneficial for chronic LBP. Although the potential exists for distraction therapies to affect the disc biomechanically, their effect on intradiscal stress is debated.

PURPOSE: To determine if distraction alone, distraction combined with flexion, or distraction combined with extension can reduce nucleus pulposus pressure and posterior annulus compressive stress in cadaveric lumbar discs compared with simulated standing or lying.

STUDY DESIGN: Laboratory study using single cadaveric motion segments.

OUTCOME MEASURES: Strain gauge measures of nucleus pulposus pressure and compressive stress in the anterior and posterior annulus fibrosus.

METHODS: Intradiscal stress profilometry was performed on 15 motion segments during 5 simulated conditions: standing, lying, and 3 distracted conditions. Disc degeneration was graded by inspection from 1 (normal) to 4 (severe degeneration).

RESULTS: All distraction conditions markedly reduced nucleus pressure compared with either simulated standing or lying. There was no difference between distraction with flexion and distraction with extension in regard to posterior annulus compressive stress. Discs with little or no degeneration appeared to distribute compressive stress differently than those with moderate or severe degeneration.

CONCLUSIONS: Distraction appears to predictably reduce nucleus pulposus pressure. The effect of distraction therapy on the distribution of compressive stress may be dependent in part on the health of the disc.

Keywords: Lumbar spine; Spinal manipulation; Intervertebral disk; Biomechanics; Stress profilometry

Introduction

Low back pain (LBP) is a ubiquitous problem in developed countries. The cost of LBP to the United States economy is estimated to be more than 100 billion dollars annually [1,2]. The relationship between disc degeneration and back pain is incompletely understood. Disc degeneration is a progressive process that results in biomechanical compromise of the motion segment. Nucleus pulposus pressure decreases in proportion to the degree of degeneration in persons with chronic LBP [3]. The tensile modulus and Poisson's ratio of the annulus fibrosus are likewise reduced [4]. As a result, annulus fibrosus fibers fail at lower loads leading to further degeneration [5] and abnormal spinal motion [6–8]. Although the course of disc degeneration cannot be predictably altered, many investigators are seeking ways to enhance disc physiology and retard or reverse degeneration.

Many treatments using traction (axial distraction) have been devised in an attempt to relieve LBP by affecting the disc and nerve roots. A meta-analysis of the traction literature concluded that, as a group, there was no evidence that traction therapies were beneficial for LBP [9].

FDA device/drug status: not applicable.

All work was performed at Mayo Clinic, Rochester, MN.

This study was funded by the National Center for Complementary and Alternative Medicine (NCCAM), a federal/state agency (grant # K07-AT00972).

Nothing of value received from a commercial entity related to this manuscript.

* Corresponding author. Department of Physical Medicine and Rehabilitation, Mayo Clinic, Ei 2D PMR, 200 First Street SW, Rochester, MN 55905 USA. Tel.: (507) 266-8913; fax: (507) 266-1561.

E-mail address: rgay@mayo.edu (R.E. Gay)

1529-9430/08/$ – see front matter
doi:10.1016/j.spinee.2007.07.398

Nonetheless, some randomized trials have suggested that chronic LBP might be relieved by traction methods [10–13] and these treatments continue to be used in practice. The most commonly used methods are intermittent axial traction (which includes proprietary devices such as VAX-D and DRX9000) and distraction manipulation. Distraction manipulation combines axial distraction with intermittent off-axis moments, usually flexion or extension. It is different than typical spinal manipulative therapy which uses a high velocity impulse during treatment. It is commonly used by chiropractors [14] as well as physical therapists and osteopathic and medical physicians.

Several mechanisms have been proposed to explain how distraction therapies might affect the disc. These include reducing nucleus pulposus pressure, changing the position of the nucleus relative to the posterior annulus, reducing posterior annulus stress, and changing the disc-nerve interface [15–17]. Although both axial distraction and distraction manipulation may temporarily reduce nucleus pulposus pressure [18,19], their effect on the distribution of stress in the disc is unknown.

The objective of this study was to determine the effect of distraction therapies (axial distraction, distraction with flexion, and distraction with extension) on vertical (compressive) and horizontal stress in anterior annulus, posterior annulus, and nucleus pulposus regions of the disc. We used the technique of intradiscal stress profilometry to estimate the stress in human cadaver motion segments under five conditions [20,21]. We hypothesized that all three forms of distraction would significantly reduce nucleus pulposus stress compared with axial loads simulating standing or sitting. We also hypothesized that distraction with flexion would reduce posterior disc stress more than axial distraction or distraction with extension. Finally, we sought to determine if degenerative discs were affected by distraction differently than relatively healthy ones.

Materials and methods

Specimens

Ten fresh, frozen (−20°C) cadaveric lumbar spines (L1–S1) with mean age of 66.4 years (SD 13.8 years, range 40 to 82) were chosen for testing. These spines were screened for HIV/AIDS, Hepatitis B and C, tuberculosis, and Creutzfeldt-Jakob disease. Prospective specimens were imaged with anterior-posterior and lateral radiographs; those with severe osteoporosis, posttraumatic deformity, bone pathology, or significant anatomical anomaly were excluded. Spines with diffuse (multilevel), severe degenerative changes that might make stress profilometry testing difficult were also excluded.

Cadavers were thawed overnight in a refrigerator and L1 through S3 was removed en bloc. The iliotransverse ligaments were sacrificed in this process. Nonligamentous soft tissues were then removed leaving intact the lumbar vertebral bodies and all ligamentous structures including anterior longitudinal ligament, posterior longitudinal ligament, interspinous ligaments, intertransverse ligaments, and facet joint capsules. Each specimen was divided into either two or three separate vertebra-disc-vertebra units, yielding 25 motion segments. K-wires were placed in the vertebral bodies and facet joints and each motion segment was potted in circular acrylic fixtures using polymethylmethacrylate. A custom jig kept the superior and inferior fixtures parallel to each other and to the plane of the disc. Specimens were kept moist with saline-soaked toweling during preparation and testing.

Preliminary testing

The degree of distraction force and flexion-extension moments necessary to simulate these treatments in isolated motion segments was unknown. Studies have reported the amount of vertebral displacement occurring during traction [22–24] and distraction manipulation [16] in vivo or in cadavers. Therefore, we conducted preliminary tests with four randomly chosen lumbar motion segments to estimate the forces needed to produce similar displacements. Distraction of 90 N produced an average increase in posterior disc height of 1.8 mm. Adding a pure moment of 5 Nm to the distracted motion segments produced an average angular displacement of 4.3° in flexion and 4.5° in extension. These displacements were similar to those previously reported to occur during distraction. An axial load of 500 N was used to simulate the load on the lumbar spine during quiet standing and 300 N to simulate lying (nonweightbearing) [25].

The transducer (Model OrthoAR; Medical Measurements, Inc., Hackensack, NJ, USA) was previously shown to accurately measure positive hydrostatic pressure up to 2 MPa [26] but the linearity of measurements in the negative range had not been reported. Because negative values might be encountered during distraction, negative pressure values (from a custom calibration chamber) were plotted against the transducer output. The response was linear to −30 kPa (−225 mmHg) with R^2=0.9996. This range includes the negative pressures reported to occur during distraction therapies [18,19].

Intradiscal stress profilometry technique

The technique of intradiscal stress profilometry was performed as described by McNally and Adams [20]. Measurements were obtained with a high-pressure strain gauge transducer mounted on a blunt 1.3 mm×15 cm needle. By pulling the transducer through the disc at a constant rate, a ‘‘stress profile’’ is produced. Stress in the normal nucleus pulposus is isotropic (equal in all directions) but stress in the annulus is typically anisotropic. Therefore, the transducer was oriented to measure both the vertical and horizontal stress values in each specimen. The transducer output from the annulus (oriented to detect vertical or compressive stress) has been shown to be proportional to the compressive stress perpendicular to the transducer-sensing surface [21].

Biomechanical testing set-up

The potted motion segments were attached to a custom testing device that could apply pure bending moments and axial compression or distraction simultaneously (Fig. 1). The lower vertebra was centered on a 6 degrees of freedom load cell (JR3; Woodland, CA, USA) and maintained in a neutral (0 moment) position with respect to the global coordinate system. Compression and distraction loads were applied to the upper vertebra using pneumatic actuators. Pure moments in flexion or extension were applied with a pulley apparatus fixed to the upper acrylic fixture with force supplied by pneumatic actuators. Angular displacement of the upper and lower fixtures (relative to the transverse or X axis) was measured with miniature tilt sensors with a resolution of 0.03° over their 20° range (Model CXTLA02; Crossbow Technology Inc., San Jose, CA, USA). The transducer was extracted by a stepper motor/pulley system that pulled a cable attached to the needle hub at 2 mm/second. LabVIEW software (National Instruments Inc., Austin, TX, USA) was used for data acquisition and to control transducer extraction. Data was collected at 30 Hz. The transducer was calibrated using a custom pressure chamber and a known amount of positive and negative pressure before tests.

Biomechanical testing

The 21 remaining motion segments were tested in the same manner. A preload of 300-N compression was applied for 30 minutes to expel excess fluid [20]. A 1.3 mm spinal needle with stylet (ground to a point) was then introduced into the anterior disc and advanced in the mid-sagittal plane through the posterior annulus under fluoroscopic guidance (Fig. 2). This created a track for the transducer midway between the vertebral end plates. The guide needle was removed and the blunt transducer needle with transducer inserted and oriented to measure the vertical component of stress. The first condition was then applied to the motion segment. The cable from the needle hub to a stepper motor/pulley was properly aligned and the transducer was withdrawn at 2 mm/second. The needle was then reinserted to measure the horizontal component of stress and again extracted. Each of five test conditions were applied in a constant order: 1) axial compression 300 N (simulation of nonweightbearing or lying) [25], 2) axial compression 500 N (simulation of relaxed standing) [25], 3) axial distraction 90 N (simulation of axial distraction in neutral or traction), 4) axial distraction 90 N and extension 5 Nm (simulation of extension-distraction), and 5) axial distraction 90 N and flexion 5 Nm (simulation of flexion-distraction). There was at least 1 minute between conditions to allow for viscoelastic recovery.

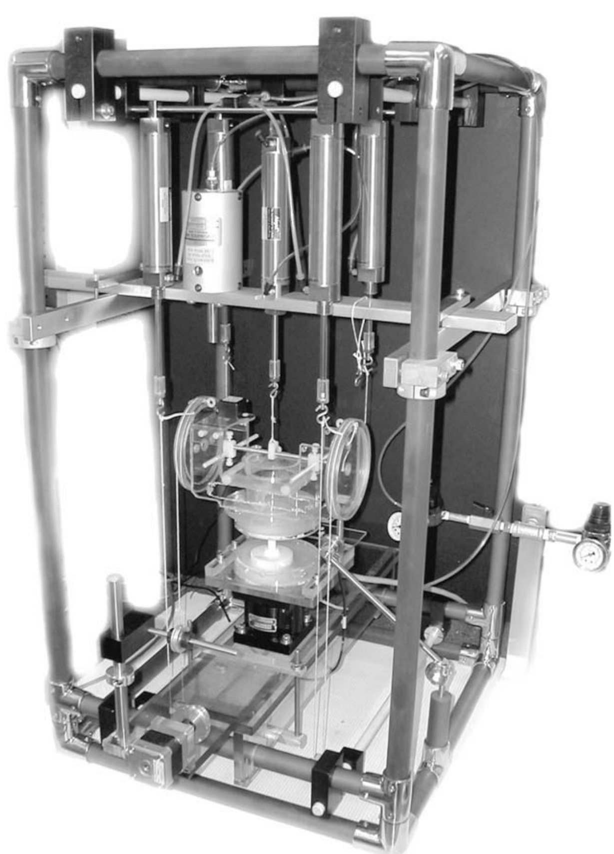

Fig. 1. Spine testing apparatus.

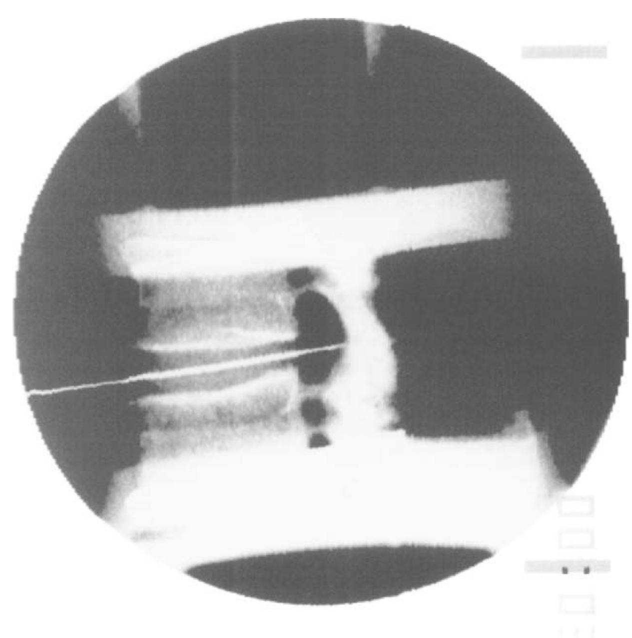

Fig. 2. Path of guide needle and transducer in the intervertebral disc.

Grading of disc degeneration

After testing, each disc was sectioned in sagittal and coronal planes and graded by two observers (an orthopedic spine surgeon and a rehabilitation physician) as normal (grade 1), mild, moderate, or severe (grades 2, 3, or 4, respectively) according to the scale of Adams et al. [5]. In the case of a disagreement between observers, a third observer (an orthopedic spine surgeon) determined the final grade. All graders were blinded to results of individual motion segment tests.

Data reduction and analysis

The relative stress values in the posterior, middle, and anterior disc regions were examined by partitioning the data into thirds. Because these regions could best be identified on profiles collected during compressive loading, each 500-N stress profile was reviewed to ensure that the middle third of the data was consistent with the hydrostatic region, which represented the functional nucleus pulposus [20]. The anterior and posterior thirds of the data (excluding the outermost data points with a precipitous drop in stress) were taken to represent the anterior and posterior disc regions (annulus fibrosus). Vertical and horizontal data were analyzed separately for each test condition in each motion segment. Peak vertical stress values were calculated for the anterior and posterior regions by averaging the single highest point value with the point values before and after it (an average of 3 point values).

The effect of the five conditions on regional vertical and horizontal stress values was examined using repeated measures ANOVA. When global F-tests were significant ($p<.05$), pairwise comparisons (contrasts) of nucleus stress (pressure) were made between the axial compression (500 N and 300 N) and each of the three distracted conditions. Because of the limited number of motion segments, the degenerative grades were collapsed into low degeneration (grades 1 and 2) and high degeneration (grades 3 and 4) groups. The effect of test condition and degeneration were evaluated using two-way ANOVA with repeated measures; generalized estimating equations were used to account for the correlation of the data within motion segments. After this, analysis using one-way ANOVA for repeated measures was performed by degenerative group. Finally, the distribution of vertical stress among the anterior, nucleus, and posterior disc regions was qualitatively examined in each of the five conditions. Analyses were carried out with SAS (SAS Institute Inc., Cary, NC). An α level of .05 (two-tailed) was used for all tests.

Results

Three motion segments from a single spine (L1–2, L3–4, and L5–S1) were excluded as a result of unexpected pathology found upon grading. Two more L5–S1 motion segments could not be tested because of difficulty in obtaining stable potting, so the one remaining L5–S1 segment was excluded. Data from the remaining 15 motion segments (9 lumbar spines) were analyzed. Distribution of disc levels was L1–2 (2), L2–3 (5), L3–4 (3), and L4–5 (5). The effect of disc level was not formally examined because of the small sample size and the risk of type II error; nonetheless, ANOVA indicated no large differences between disc levels suggesting that pooling of the levels was appropriate.

Distribution of degenerative grades was grade 1 (3), grade 2 (5), grade 3 (4), and grade 4 (3). This resulted in 8 in the low degeneration group and 7 in the high degeneration group. Only one cadaver was female. Fig. 3 shows a representative set of vertical stress profiles for five conditions recorded from a single disc with mild (grade 2) degeneration. These profiles are representative of the raw data collected.

Regional vertical and horizontal stress values

Table 1 shows the regional vertical and horizontal stress values for the five conditions for all specimens combined, low degeneration discs (n=8), and high degeneration discs (n=7). The regional (mean) vertical stress values for all specimens combined during each of the five conditions are shown graphically in Fig. 4. The vertical and horizontal stress values in each disc region are compared in Table 2. Vertical and horizontal values were statistically different (paired t tests) only in the anterior disc region and only for some conditions. Vertical and horizontal peak values in the posterior and anterior disc regions are also included in Table 2 but no statistical comparison was made as the peak values within a region did not always coincide with the same point value position.

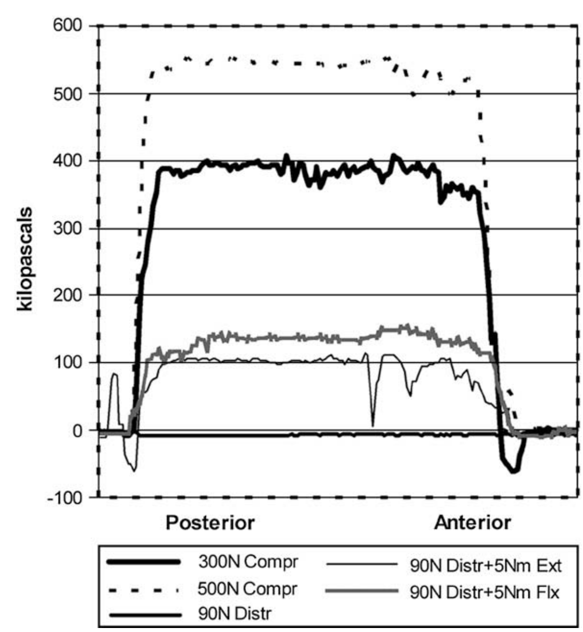

Fig. 3. Vertical stress profiles in a grade 2 (mildly degenerated) L3–4 motion segment (five conditions).

Table 1
Mean (SD) vertical and horizontal stress values (kPa) in three disc regions for five test conditions

Region	300 N compression	500 N compression	90 N distraction	90 N distraction, 5 Nm extension	90 N distraction, 5 Nm, flexion
Anterior h					
All	231.4 (139.9)	305.0 (188.8)	−0.7 (9.1)	61.9 (59.0)	104.6 (44.9)
Low	302.4 (134.3)	383.2 (202.3)	2.1 (10.7)	94.2 (53.0)	111.8 (49.2)
High	150.3 (101.0)	215.6 (134.1)	−3.8 (6.1)	25.0 (43.1)	96.3 (41.6)
Anterior v					
All	269.9 (141.0)	331.3 (185.6)	3.1 (11.8)	76.4 (56.5)	124.6 (46.2)
Low	345.7 (121.5)	411.5 (190.0)	5.5 (8.9)	107.8 (48.5)	135.6 (56.5)
High	183.2 (112.8)	239.7 (141.0)	0.4 (14.8)	40.6 (43.6)	112.0 (30.3)
Nucleus h					
All	337.9 (160.4)	447.6 (228.8)	0.9 (17.2)	89.7 (74.1)	120.7 (73.5)
Low	434.1 (115.4)	563.5 (222.8)	7.3 (15.9)	132.9 (66.1)	146.6 (72.8)
High	227.9 (134.2)	315.2 (160.8)	−6.4 (16.7)	40.3 (48.8)	91.1 (67.2)
Nucleus v					
All	341.7 (158.1)	439.9 (228.6)	2.9 (10.3)	92.5 (68.1)	119.3 (76.6)
Low	430.4 (123.1)	552.9 (223.5)	6.5 (9.1)	130.2 (64.2)	149.2 (76.3)
High	240.3 (134.7)	310.8 (164.9)	−1.3 (10.7)	49.4 (44.1)	85.1 (65.9)
Posterior h					
All	287.6 (125.0)	391.9 (207.5)	−0.7 (14.7)	84.7 (59.9)	91.1 (78.2)
Low	355.3 (97.3)	478.1 (211.9)	2.0 (18.0)	120.0 (51.6)	123.3 (70.2)
High	210.1 (110.9)	293.5 (163.9)	−3.9 (10.3)	44.4 (41.2)	54.3 (74.5)
Posterior v					
All	275.5 (144.9)	369.0 (210.3)	1.3 (8.9)	82.1 (62.5)	87.3 (75.7)
Low	345.4 (120.2)	449.8 (217.6)	2.3 (11.7)	112.6 (66.2)	113.8 (77.6)
High	195.6 (134.7)	276.8 (171.2)	0.2 (4.8)	47.3 (36.9)	57.1 (66.1)

h, horizontal; v, vertical; All, all specimens combined (n=15); Low, low degeneration (grades 1 and 2, n=8); High, high degeneration (grades 3 and 4, n=7); Posterior, posterior annulus; Nucleus, nucleus pulposus; Anterior, anterior annulus.

Effect of distraction on disc stress measures

Vertical and horizontal stress values in the nucleus pulposus were nearly the same (Table 1), suggesting that the measures from the nucleus were consistent with nucleus pressure. Nucleus pressure, posterior vertical stress, and anterior vertical stress were all significantly decreased in the three distracted conditions as compared with either 300 N or 500 N compression (pairwise post hoc contrasts, $p<.001$ for each comparison). This was also true when both low-and high-degeneration groups were analyzed separately with one exception. Comparison of anterior vertical stress in high degeneration discs between 300-N compression and flexion-distraction was not significant ($p=.76$). Axial distraction (without flexion or extension) yielded the lowest mean nucleus pressure. Compared with 300-N compression (simulated lying), nucleus pressure decreased 99% with axial distraction, 73% with extension-distraction, and 65% with flexion-distraction. Statistical analysis of the differences between disc regions was not carried out.

Effect of flexion-distraction and extension-distraction on stress distribution

The mean vertical stress values in each disc region of low degeneration discs (grades 1 and 2) during flexion-distraction and extension-distraction are shown in Fig. 5. The highest mean value for both conditions was in the nucleus. There was little difference between the two conditions in any disc region. The same data for high degeneration discs (grades 3 and 4) are shown in Fig. 6. A formal statistical comparison was not made because of the small numbers in each group. Inspection of Fig. 6 suggests no statistical difference in vertical (compressive) stress between distraction

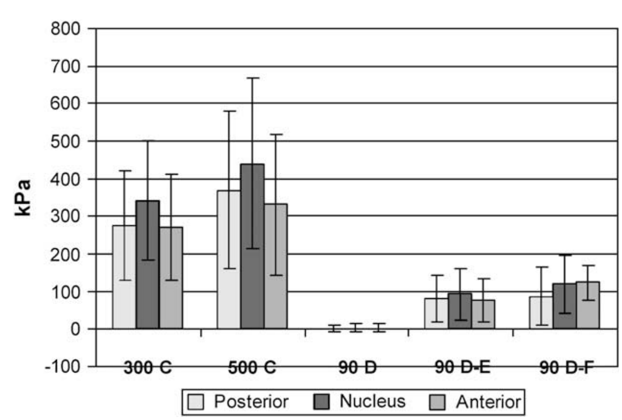

Fig. 4. Mean (SD) regional vertical (compressive) stress during five load conditions (all specimens, n=15), (C = compression, D = distraction, E = extension, F = flexion). Differences between compression (either 300 N or 500 N) and each distraction condition were statistically significant in all disc regions (repeated measures ANOVA with post hoc contrast tests, $p<.001$ for all comparisons).

Table 2
Comparison of mean (SD) and peak vertical and horizontal stress (kPa) values in five conditions (n=15)

Region	300 N compression	500 N compression	90 N distraction	90 N distraction, 5 Nm extension	90 N distraction, 5 Nm flexion
Anterior v	269.9 (141.0)	331.3 (185.6)	3.1 (11.8)	76.4 (56.5)	124.6 (46.3)
Anterior h	231.4 (139.8)	305.0 (188.8)	−0.7 (9.1)	61.9 (58.0)	104.6 (44.9)
p Value*	0.008	0.139	0.226	0.004	0.009
Nucleus v	341.7 (158.1)	439.9 (228.6)	2.9 (10.3)	92.5 (68.1)	119.3 (76.6)
Nucleus h	337.9 (160.4)	447.6 (228.8)	0.9 (17.23)	89.7 (74.1)	120.7 (73.6)
p Value*	0.574	0.244	0.435	0.334	0.737
Posterior v	275.5 (144.9)	369.0 (210.3)	1.3 (8.9)	82.1 (62.5)	87.3 (75.7)
Posterior h	287.6 (125.0)	391.9 (207.5)	−0.7 (14.7)	84.7 (59.9)	91.1 (78.2)
p Value*	0.435	0.177	0.597	0.625	0.589
Peak posterior v	380.7 (161.6)	505.0 (220.3)	42.8 (67.9)	130.9 (59.4)	123.9 (77.5)
Peak posterior h	388.4 (158.2)	505.1 (236.7)	21.7 (24.1)	121.1 (72.5)	146.2 (101.9)
Peak anterior v	367.5 (138.5)	476.7 (207.7)	31.1 (22.9)	117.2 (66.5)	198.8 (92.3)
Peak anterior h	336.9 (153.9)	441.2 (223.1)	11.9 (11.1)	95.3 (70.9)	159.6 (54.1)

h, horizontal; v, vertical.
*Paired *t* test between v and h values.

with flexion and distraction with extension. Yet, vertical stress appeared to be distributed differently in these conditions when the trend from anterior to posterior was considered. During extension-distraction of high degeneration discs, vertical stress was greater in the posterior and nucleus regions and least in the anterior region. A very different pattern was seen during flexion-distraction. The vertical stress appears to decrease from anterior to posterior suggesting a gradient.

Discussion

In this experiment, all three distraction conditions temporarily reduced nucleus pressure compared with simulated standing and lying. The largest effect was observed during axial distraction without flexion or extension which reduced pressure to near zero. Degenerated discs responded differently than relatively normal discs; they had greater temporary net reductions in nucleus pressure. Although not examined quantitatively, the distribution of stress among disc regions in normal or minimally degenerated discs (grade 1 or 2) was similar in flexion-distraction and extension-distraction. This could be a result of the nucleus being pressurized and efficiently distributing the stress. In discs with higher amounts of degeneration (grades 3 and 4), the nucleus had much less pressure when extension or flexion was introduced indicating that stress distribution may have been dependent on the moment applied to the segment. Flexion-distraction resulted in compressive stress being temporarily qualitatively lower in the posterior region compared with the nucleus and anterior regions. Conversely, extension-distraction of degenerated discs yielded similar vertical stress in all three regions.

Nucleus pulposus pressure has been used to calculate axial loads on the spine [25,27]. This is appropriate because the normal nucleus acts as a fluid with the stress being hydrostatic or isotropic (equal in all directions). As such, it is a scalar quantity that can be measured with strain gauge technology. Quantifying stress in the annulus is more problematic. Annular stress is not isotropic but anisotropic with different vertical and horizontal components [5]. Pressure and stress have the same SI unit of measure (Pascal). Although strain gauge transducers have been used to estimate stress in the annulus, it is debatable exactly what the measurements represent. Rao et al. interpreted the output from strain gauges placed in the annulus (to detect vertical stress) to be ‘‘intradiscal pressure in the axial direction’’ [28] despite the fact that pressure is nondirectional. McMillan et al. attempted to determine the validity of strain gauge transducer measures in the annulus and found the output of their transducer to be linearly proportional to the vertical force applied to the disc. They reasoned that the output was also proportional to the compressive stress perpendicular to

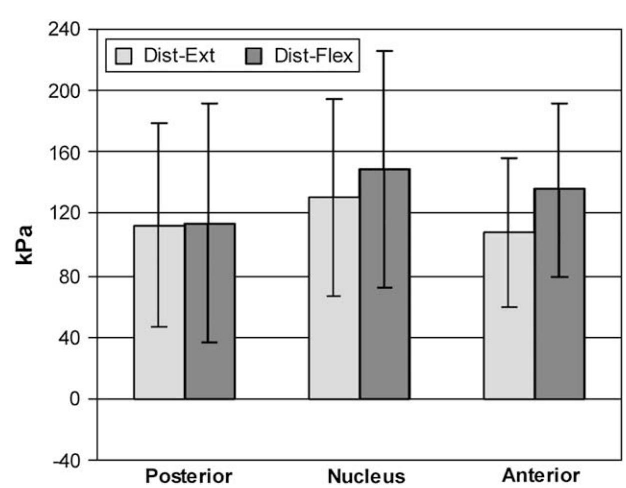

Fig. 5. Mean (SD) regional vertical stress in low degeneration discs (grade 1 and 2) during extension-distraction and flexion-distraction (n=8).

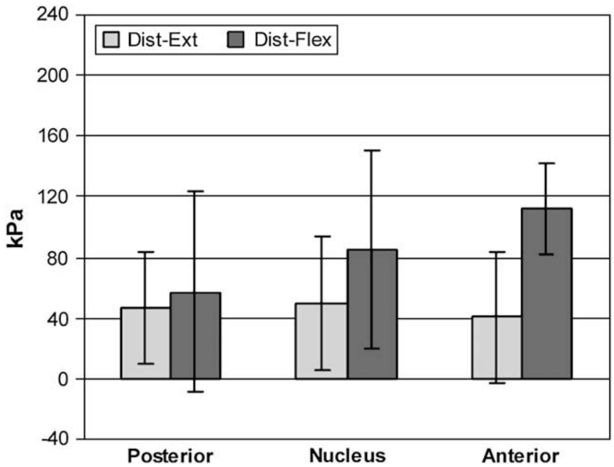

Fig. 6. Mean (SD) regional vertical stress in high degeneration discs (grade 3 and 4) during extension-distraction and flexion-distraction (n=7).

the transducer membrane [21]. Interestingly, they found that the same calibration coefficient was applicable to liquids, nucleus pulposus, and all but the outer 2 to 4 mm of the annulus fibrosus. Although we recorded both horizontal and vertical stress components in this experiment, we were primarily interested in the ability of distraction to ‘‘unload’’ the disc, that is, reduce the vertical or compressive stress. Therefore, we have referred to the vertical measures as vertical stress. Vertical stress measures in the nucleus were essentially the same as the horizontal measures, and therefore were interpreted as nucleus pressure.

The normal lumbar nucleus is displaced anteriorly by extension and posteriorly by flexion when lying [29,30] but changes in nucleus pressure and position in degenerated discs are not as predictable [29,31,32] and degenerated discs have been noted to bulge posteriorly with extension [30,33]. Our findings are consistent with reports that degenerated discs may respond differently from healthy discs to flexion and extension [30,31,33] and extend that observation to include flexion and extension combined with distraction. The qualitative differences we observed in stress distribution between relatively healthy and degenerated discs might be because of the degenerated discs being unable to generate or maintain nucleus pressure. They may also be explained in part by anatomy. When the motion segment is extended, the facet joints contact each other and the center of rotation moves posteriorly toward the facets, causing the anterior disc space to widen. This effectively shields the posterior disc from further compression [32]. Conversely, flexion-distraction of degenerated discs may result in anterior compression and an anterior shift of the center of rotation. This appears to produce a stress distribution with the least compressive force in the posterior annulus. These observations suggest that the normal response of lumbar discs to flexion and extension is dependent to some extent on the health of the disc.

The primary mechanical theory underlying the use of distraction therapies for disc herniation is that they reduce nucleus pressure and pull peripheral nucleus tissue toward the center of the disc [34–36]. Distraction has been shown to produce temporary negative pressure in the nucleus of living patients [18]. Nucleus pressure in the present experiment became negative during axial distraction in 4 of 8 low degeneration discs but in only 1 of 7 high degeneration discs. Gudavalli et al. [19], recorded negative pressures during flexion-distraction in a whole cadaver model but we did not observe that in this study. This may have been a result of violation of the annular ‘‘seal’’ with the transducer, but that is unlikely considering the instruments used by Gudavalli et al. were similar to the ones we used. Other possible explanations include dissimilar forces used during flexion-distraction or the difference between whole cadaver and single motion segment models. Gudavalli et al. used intermittently applied, short-duration forces and continuous measurement. We measured pressures 1 to 2 minutes after the force was applied which might also explain this difference.

This study has several weaknesses that should be considered. First, a cadaver model may not accurately represent the response of the disc to loading in vivo. At this time there is no safe and acceptable method of obtaining similar in vivo measurements in humans. The age of tissue donors was generally older than persons presenting with discogenic back pain. The effects of freezing and thawing lumbar spine tissues is not thought to significantly affect the physical properties of human spine specimens [37]. Yet, dehydration and prolonged exposure to room temperatures are known to affect their material properties. The specimens in this experiment were kept moist [38] and the exposure to room temperature minimized. Our results were not likely affected by soft-tissue changes because of exposure. Second, the method we used to simulate treatments is most consistent with intermittent traction and lasting 1 to 2 minutes. It may not reflect the exact time course of stress change during shorter treatments such as distraction manipulation. Third, although the output of the transducer we used has been shown to be proportional to the applied compressive stress (perpendicular to the sensing element), it may not provide a highly accurate measure of compressive stress. Nonetheless, it provides a reasonable measure of stress change within specimens [21]. Fourth, we excluded all L5–S1 motion segments from our data. The L5–S1 segment has different ligamentous anatomy and slightly different kinematics than the other lumbar segments. Further, it can be difficult to secure and test. We did encounter difficulties with potting and as a result elected to exclude the single L5–S1 motion segment with usable data from analysis. Fifth, the results must be considered carefully in light of the small sample size and risk of error. Yet, the study was designed as a repeated measures study to maximize the power.

Our findings provide insight into the mechanical effects of distraction therapies but they do not establish a mechanism by which distraction might benefit those with back pain or sciatica because of disc injury. It is possible that the motion or change in stress results in mechanobiological events that lead to pain relief or promote disc health [39,40]. Studies using both animal and in vitro models have demonstrated that mechanical stress may play a role in the regulation of both degradative and anabolic processes in discs [41–43]. Kroeber et al. [42] using a rabbit model found that degenerated discs (created by compression) treated with distraction had restoration of disc height and histological evidence of regeneration. Although the method of producing degeneration in that model can be questioned, the results provide preliminary evidence that distraction might potentially have a beneficial affect on disc physiology. Distraction might also reduce local stress peaks in the annulus fibrosus which are thought to produce LBP [44]. Further studies are needed to establish a clear clinical benefit of distraction therapies. Additionally, studies are needed to examine the relationship between stress distribution and clinical markers of disc biology such as the degree of nucleus hydration [45].

Acknowledgments

The authors would like to thank Jonathan Bridges for technical assistance.

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