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Disc Prolapse

Evidence of Reversal With Repeated Extension

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Study Design. A basic science study that used a porcine cervical spine model to produce disc prolapse subsequently exposed to an extension protocol.

Objective. This study investigated whether extension or combined extension and side flexion could move the displaced portion of nucleus from the anulus towards the nucleus.

Summary of Background Data. Previous research has established that repeated flexion can create disc prolapse, the question here is whether repeated extension can reverse the process.

Methods. The C3/4 segments of 18 porcine cervical spines were dissected and potted in cups. Specimens were preloaded, then axially compressed (1472 N), and repeatedly rotated in either pure flexion or combined flexion and side flexion at a rate of 0.5°/s. Specimens that prolapsed were axially compressed and repeatedly and rotated into extension.

Results. Based on a blinded radiologist's review of the radiograph images, all 18 specimens contained healthy discs before testing, but after testing 2 of the 18 specimens had endplate fractures, whereas 11 of the 18 specimens had prolapsed. Prolapsed nucleus was reduced in 5 of the 11 prolapsed specimens after the reversal testing, whereas the remaining 6 did not change. Subclassification analysis revealed that the prolapsed discs that centralized had significantly less disc height loss ($P < 0.01$). Neither the classification of the herniation (circumferential or radial) nor the angle of lordosis of the specimens was linked to the behavior of the specimens.

Conclusion. This study showed that with repeated flexion, in porcine cervical spines, disc prolapse was initiated and that the displaced portion of nucleus can be directed back towards the center of the disc in response to particular active and passive movements/positions.

Key words: intervertebral disc prolapse, repeated extension, disc height. **Spine 2009;34:344–350**

Numerous studies have investigated the loading mechanisms necessary to cause disc failure.[1–6] Collectively, this work suggests that repeated forward bending causes stresses both in the nucleus and in the anulus resulting in prolapse and herniation. Repeated extension is a treatment used by manual therapists as it is thought to assist in returning the displaced portion of the nucleus back towards the center of the disc. This study was designed to enhance understanding of this possible mechanism.

McKenzie[7] proposed that the direction of spine movement that centralizes radiating symptoms precisely corresponds with the direction in which a portion of the nucleus has abnormally migrated. Further, successful centralization is dependant on a hydrostatically intact nucleus that is contained within the outer anulus. Donelson *et al*[8] reported that patients, who could not achieve centralization of symptoms as a result of repeated movements, did not respond well to conservative therapy and generally had a poor treatment outcome. Subsequently, Donelson *et al*[9] investigated the theory that centralization is dependent on a competent anulus (the outer border not breached) by investigating the correlation of the McKenzie classification of the symptom response to movement, to whether or not the anulus was competent, as determined by discogram. Ninety-one percent of those that centralized had an intact anulus suggesting possible grounds for this component of the McKenzie theory.

From a biomechanical perspective, the McKenzie explanation seems possible. Flexion postures cause an increase in the hydraulic stress (flow-related) on the posterior anulus, and a large increase in the *in vivo* nuclear pressure (static). Supporting this argument, Aultman *et al*,[2] repeatedly flexed specimens where the flexion axis was moved 30° to the left of the sagittal plane. Herniations were developed in the right postero-lateral portion of the disc. Thus, the site of the nucleus breach of the inner anulus was determined by the bending axis, and subsequent stress distribution, a finding also reported by Tsantrizos *et al*.[10] Tampier *et al*[11] further elucidated the herniation process by documenting the formation of small clefts in between the layers of the anulus through which the nucleus pulposus was "pumped." In this way, the herniation progressed layer by layer as the anulus fibers delaminated to allow flow through small separations between anulus collagen fibers.

Adams[12] investigated the effects of extension bending on healthy lumbar intervertebral disc (IVD) and found that 2° of extension increased the maximum compressive stress within the posterior anulus by an average of 16%, compared with the neutral posture, in healthy IVD. However, in degenerate spines, the results were more variable. In 7 of 19 degenerated specimens extension caused a reduction, of up to 40%, in the maximum compression in the posterior anulus, whereas in the other degenerate discs, the compression was increased by 43% relative to the neutral posture. Adams[12] suggested that the variability in the stress gradient across the disc created by extension may be a reasonable explanation for

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the variance in the success or failure of the McKenzie approach in discogenic patients.

The objective of this study was to create *in vitro* disc prolapse in the discs of spine motion segments and then evaluate the effects of extension movements on the position of the displaced portion of the nucleus in the anular layers. It was hypothesized that (1) repeated motion, opposite to the motion that caused the disc to prolapse, would reverse the position of the displaced portion of nucleus; and (2) discs that would not respond to reversal testing would have a portion of the nucleus displaced circumferentially in the anulus or have a full herniation, with the displaced portion of the nucleus breached through the outer anulus.

Materials and Methods

Creating Disc Prolapse (Failure Procedure)

The C3–C6 segments of 18 porcine cervical spines (approximately, 80 kg pigs) were dissected from porcine spines that had been bagged and frozen immediately postmortem and thawed at room temperature for 12 to 15 hours before dissection. A lateral radiograph image (Mercury Modular radiograph, 007 mas, 100 ma, 54 kvp) of the C3–C6 intact segments was taken before the C3/4 osteoligamentous specimens (intact IVD, facets, and intervertebral ligaments) were dissected. The C2/3 and C4/5 IVD were examined for degeneration and all specimens were classified as grade 1 on Galante[13] scale of disc degeneration. Specimens were fixed with 18 gauge steel wires and cemented with nonexothermic dental plaster (Denstone; Miles Inc., South Bend, IN) into ultra high-density polyethylene cups. To track the position of the nucleus radiologically, 0.55 mL of a radio-opaque mixture was injected into the C3/4 IVD through the anterior anulus using a 21-gauge needle. The mixture consisted of barium sulfate, blue dye (250 mg Coomassie brilliant blue, 97.25 mL of distilled H_20, and 2.5 mL of methanol), and distilled water, in a 2:1:2 ratio, together with some nucleus material harvested from an adjacent segment. Two specimens did not include the harvested material. This harvested material was used to eliminate the possibility that the less viscous barium sulfate mixture could herniate through anular clefts/ruptures where the more viscous nucleus would not. The needle aperture was sealed with superglue after the injection. The specimen, wrapped in a layer of saline (0.9% NaCl) soaked plastic-backed material and a layer of polythene film, was placed in a servo hydraulic dynamic testing machine (model 8511; Instron Canada, Burlington, Ontario, Canada) (Figure 1), which had been modified to apply both axial compression and single plane pure moments simultaneously. The lower cup, containing the C4 segment, was free to translate to remove artificial stiffness. Each specimen was preloaded (260 N for 879 second) to reverse the effects of freezing during which time the Instron testing machine algorithm found a position of zero torque for the specimen. After the preload protocol, the potted specimens were removed from the jig and anterior and lateral view radiograph images were taken. A jig to support the upper and lower cups was used to maintain a standard frontal and transverse plane position of the specimen during the radiograph process. As earlier pilot work had shown that the position of the nucleus was not altered if the specimen was x-rayed in a predetermined sagittal plane position or as determined by the stiffness of the specimen after testing, it was decided not to fix the sagittal plane position for radiograph, thus avoiding the risk of varying the compression of the specimens in addition to making it more difficult to maintain the standard frontal plane position.

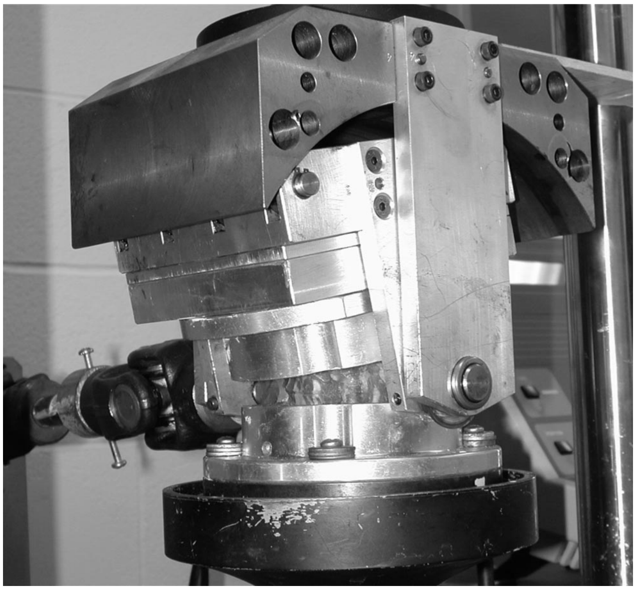

Figure 1. A photograph of a specimen, wired and cemented in cups, positioned in the servohydraulic jig. The plate and top cup rotated causing the determined motion. The specimen was wrapped in saline soaked material during the testing.

To identify the range of bending angles to be used for dynamic failure testing, the torque-angular deformation relationship of each specimen was recorded. To do this, each specimen was axially compressed (1472 N) and rotated 5 times, in either pure flexion or combined flexion and side flexion (depending on the direction of the test motion), at a rate of 0.5°/s during which the torque-angular deformation curve was plotted. The angle at which the stiffness substantially increased was the maximum angle used in the dynamic testing, and an angle 10° less than the maximum was the minimum angle used.

To create partial herniations, the specimens were repeatedly flexed under an axial compression load of 1472 N at a rate of 45°/s and a frequency of 1 Hz. Four specimens were subjected to pure flexion load, whereas 14 were exposed to combined flexion and side flexion. Given the disc height concerns, it was decided to test the specimens with what is considered a more potent repetitive motion than pure flexion, combined flexion with side flexion, to accelerate the prolapse and reduce the disc height loss that was occurring. The radiograph process was repeated at 10-minute intervals for the first 30 minutes of testing and subsequently at 30 minute intervals. If early tracking of a portion of the nucleus was identified in a specimen more frequent radiographs were taken to prevent full herniation, rather than prolapse, of the specimen (Table 1). Postfailure radiograph images were taken after completion of the failure test (postfailure images).

Reversal Testing

Prolapse was defined as a posterior/lateral shift of the nucleus of at least 50% (2–3 mm) of the pretest width of the anulus. Specimens that had prolapsed were immediately put through a reversal test which consisted of 10° (from the position of zero torque determined during preload) of repeated extension or combined extension and side flexion of the specimen at a rate of 45°/s and a frequency of 1 Hz. Axial compression of 260 N was used for the reversal test after 2 tests at higher compression

Table 1. Although Under 1472 N of Axial Compression, the Repetitions (Reps.) and Direction of Motion Used to Create Disc Prolapse Are Shown

	Reps. of Test Motion			Reps. of "Treatment" Motion		
Specimen	Flexion	Flexion/Side Flexion	Reversal Test Compression (N)	Extension Reps.	Extension/Side Flexion	Sustained Extension (mins)
K	5400		N/T	—		
L	5400		867	1200		
N	5400		1472	1200		
M18	10,800		N/T	—		
O11		9000	260	900		
O13		3600	260	1800		
O132		5400	260		1800	
O16		5400	N/T	—		
O162		1800	260		1800	
O173		14,400	N/T			
O18		1800	260		2700	
O23		2400	260	900		
			606	2700		
O232		4500	N/T	—		
O233		4500	N/T	—		
O24		900	260	—	—	15
			260		900	
O242		1800	260		5100	
O25		3300	N/T	—		
N32		2700	260		900	

Subsequent reversal test specifications are shown on the right-hand side of the table. Testing of specimens that had not failed but that had severe disc height loss was discontinued.
N/T indicates not tested.

levels (867 and 1472 N) raised concerns about disc height loss. The reversal testing was discontinued when the displaced portion of the nucleus appeared to move more anteriorly towards the center of the disc or when the condition (disc height loss/retrolisthesis) of the specimen hindered interpretation of the results. Postreversal radiograph images were taken after completion of the reversal test (postreversal images).

Data Analysis

An independent and blinded radiologist reviewed the disc prolapse radiograph images on 2 occasions to:

1. Determine that the pretest discs were healthy.
2. Classify the type of failure that occurred with failure testing (no failure, endplate fracture, prolapse, herniation, retrolisthesis) and to categorize the disc height loss of the specimens.

The reversal testing images were also reviewed to:

3. Categorize the loss in the disc height of each specimen as mild, moderate, or severe.
4. Determine whether the location of the displaced portion of the nucleus in the posterior anulus of each specimen had changed and if so in what direction.
5. Determine the change in vertebral body alignment relative to that of the postfailure testing alignment (spondylo- or retrolisthesis).

The disc height of the specimens was measured by the investigator on the lateral radiograph images according to Wilke *et al.*[14] The postfailure and postreversal disc height was normalized to the disc height of the pretest (post-preload) disc height measurements. The position of the posterior margin of the nucleus was measured relative to the inferior articular process of the C3 segment. The stiffness of the specimens was recorded as the slope of the line joining the minimum to maximum angles of the repeated motion on the torque-deformation curve. The mean stiffness over the first 10 cycles of the dynamic test was considered the pretest stiffness and was compared to that of the last 10 cycles, the final stiffness. The lordotic angles of the C3–C6 spine and of the C3/4 specimen were measured as the angle between the superior endplate of the C3 vertebral body and the inferior endplate of the C6 vertebra, whereas the lordotic angle of the specimen was measured as the angle between the superior endplates of the C3 and C4 vertebral bodies.

A 2-way Pearson's correlation was used to compare the radiologists' review of the radiograph images on 2 occasions. Differences in disc height and stiffness of specimens after the failure testing were considered using a paired *t* test. Repeated measures ANOVA was used to test for significant group differences (reversed or not) in disc height and stiffness of prolapsed specimens after failure and reversal testing. Analysis of the ability of disc height post failure testing to predict the specimen response to reversal testing was performed using discriminate testing. A 1-way ANOVA was used to test for group differences (prolapsed or not) in the lordosis angle of the specimens.

■ Results

Perfect correlation scores of the radiologist review of the radiograph images on 2 occasions was found regarding the health of the specimens before testing together with the number of endplate fractures after failure testing. Significant correlation of whether the specimens prolapsed, or not, was found ($P < 0.01$, r = 0.9). One specimen that was considered not prolapsed on the first review was considered prolapsed on the second. The investigator had deemed it not prolapsed at the time of testing and had not put it through the reversal test. The correlation of whether the posterior margin and the pos-

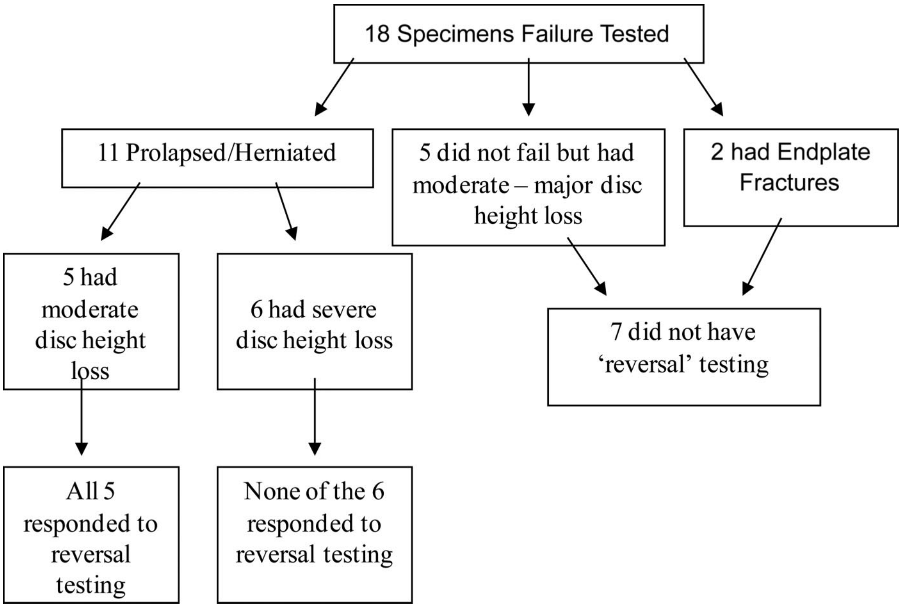

Figure 2. An overview of the results of the failure procedure and of the reversal testing shows the 5 prolapsed discs that had moderate posterior disc height loss and responded positively to reversal testing versus the 6 prolapsed discs that had severe posterior disc height loss and did not respond to reversal testing.

terior volume of the displaced portion of nucleus changed after the post reversal testing was $r = 0.83$ and $r = 1$, respectively. On the second review, the radiologist deemed that the posterior border of 2 specimens did not change after the reversal testing. He reported a clinically significant change in the posterior volume of the nucleus in both of these specimens on both reviews (Figure 2 and in more detail in Table 2). After failure testing, dissection revealed that 2 specimens had endplate fractures, whereas 11 of the 18 specimens had prolapsed. The mean disc height loss of all specimens was 55.89% (SD 15.59%) and that of the specimens that prolapsed was 53.03% (SD 18.00%). Significant increases ($P < 0.001$) from 1.31 Nm/degree (SD 0.42) to 2.44 Nm/degree (SD 0.633) in the stiffness of the 18 specimens after the failure procedure were found. Seven of the 18 specimens that underwent failure testing did not go on to have "reversal" testing as 2 of the 7 had endplate fractures with severe loss of disc height after the failure procedure, whereas the 5 others not did not prolapse.

According to the radiologist there was a positive clinical change in the displaced portion of the nucleus in 5 of

Table 2. An Independent Radiologist's Opinion of the Changes in the Condition of the Disc and the Change in the Position of the "Nucleus" With Each Stage of Testing as Seen in the X-ray Images Are Outlined

	Postfailure Test				Post-"Reversal" Test					
Specimen	Endplate Fracture Y/N	Posterior Migration of Nucleus Y/N	Lateral Migration of Nucleus Y/N	Retrolisthesis	Disc Height Loss	Reversal of Posteriorly Migrated Nucleus	Reduced Posterior Volume of Migrated Nucleus	Reversal of Laterally Migrated Nucleus	Increased Retrolisthesis	Disc Height Change
K	Y	N	N	Y	Severe			N/T		
L*	N	Y	N	N	Mod.	Y	Y	Y	N	N
N*	N	Y	N	N	Mod.	Y	Y	N	N	N
M18	N	N	N	N	Mild			N/T		
011†	N	Y	N	N	Severe	N	N	N	N	↑
013†	N	Y	Y	Y	Severe	N	N	N	Y	↑
0132†	N	Y	N	Y	Severe	N	N	N	N	N
016	Y	Y	N	Y	Severe			N/T		
0162*	N	Y	N	N	Mod.	Y	Y	Y	N	↑
0173	N	N	Y	Y	Mod.			N/T		
018*	N	Y	Y	N	Mod.	Y	Y	N	Y	↑
023*	N	Y	N	N	Mod.	Y	Y	N	N	↓
0232	N	N	N	N	Mild			N/T		
0233	N	N	Y	Y	Mild			N/T		
024†	N	Y	Y	N	Severe	N	N	N	N	↑
0242†	N	N	Y	N	Severe	N	N	N	Minor	↑ ant.
025	N	N	N	N	Mild			N/T		
N32†	N	Y	N	Y	Severe	N	N	N	N	N

*Five of the 11 prolapsed discs responded to reversal testing.

‡The 6 prolapsed discs that did not respond to reversal testing had all lost more disc height after the failure procedure than those that reversed.

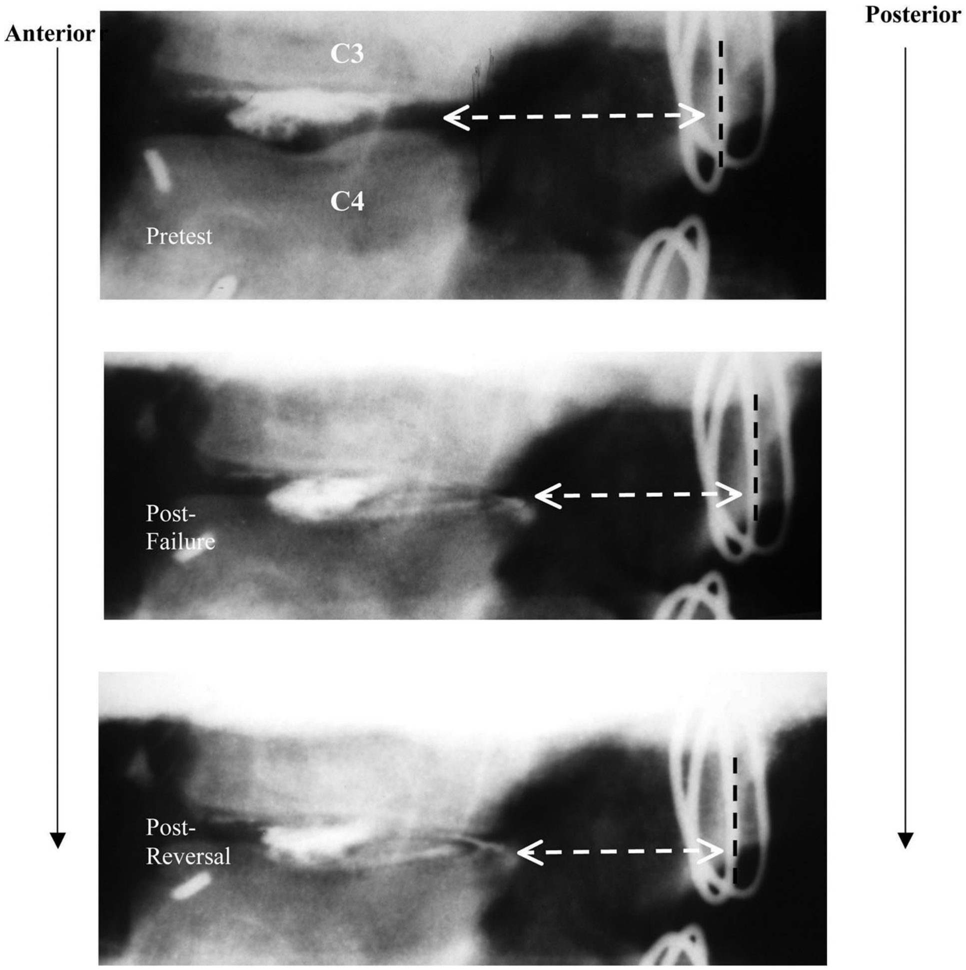

Figure 3. The pretest, post-failure and post-reversal lateral images of specimen L. This specimen was one of the five that responded to the reversal testing according to the radiologist. The distance from the posterior margin of the nucleus to the inferior articular process of C3 (black vertical line) is indicated by the white dashed line. Note some variation in the photographic magnification of the images exists and thus measurements should not be taken directly from these photographs.

the 11 prolapsed specimens after the reversal testing (Figures 3, 4); whereas in the remaining 6, the position of the displaced portion of the nucleus did not change.

The disc height loss of the 11 specimens after reversal testing was 46.49% (SD 27.46%) with no significant differences found between the specimens that reversed that those that did not. Interestingly, the postreversal results provided a subclassification of the 11 postfailure prolapsed specimens. A significant difference ($P < 0.01$) in the postfailure disc height was found between the prolapsed discs that reversed and those that did not (Figure 5). The change in position of the anterior and posterior margins of the nucleus was 2 mm (SD 2.2 mm) and 2.6 mm (SD 1.3 mm), respectively (Note the width of the posterior anulus in these specimens was in the range of 4–6 mm). No change was identified in the posterior margin of the nucleus in 2 of the 5 prolapsed specimens after the reversal testing.

The specimens that did not respond to reversal testing had prolapsed to a greater extent (more volume posteriorly and closer to the outer anulus) than those that did respond. The stiffness of the specimens increased over the course of the reversal test from 1.27 to 1.88 Nm/degree when loaded under 260 N of axial compression. When considered separately the number of repetitions of motion, the direction of motion or the maximum range of the repeated motion did not have a significant effect on the changes in disc height or distinguish between those that did not prolapse, those that prolapsed and reversed, and those that prolapsed but did not reverse. Three of the 6 discs that did not respond to and 2 of those that did respond to reversal testing had circumferential prolapses but no consistent herniation pattern was found. The lordosis angles of the spines and segments ranged from 28° to 42° and 7° to 22°, respectively, and did not distinguish between the groups. As seen in Table 1, the reversal testing that centralized the disc prolapses did so with movements in the same plane but opposite direction to the movement that caused the prolapse, in all but 1 case. In the case of O23, a specimen that failed with combined flexion and lateral flexion, was "reversal" tested with pure sagittal extension as the prolapse appeared in the sagittal plane only.

■ Discussion

Repeated pure or combined extension after disc prolapse was found to redirect the displaced portions of the nucleus back to the central part in a number of discs. The fact that not all specimens responded seems to match clinical observation that the McKenzie approach can be effective with some patients with prolapsed discs but not with others. The disc height loss after the failure procedure distinguished between specimens that responded to reversal testing and those that did not respond.

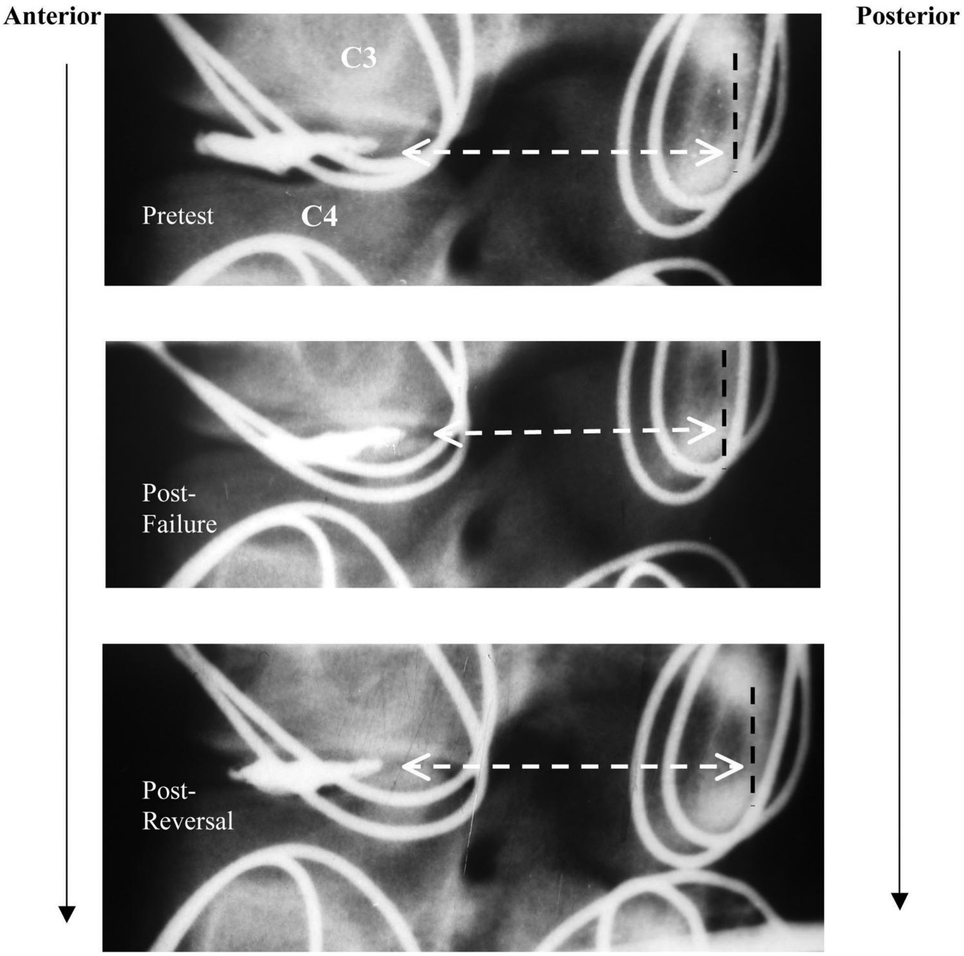

Figure 4. The pretest, post-failure and post-reversal lateral images of specimen 0162. This specimen was one of the five that responded to the reversal testing according to the radiologist. The distance from the posterior margin of the nucleus to the inferior articular process of C3 (black vertical line) is indicated by the white dashed line. Note some variation in the photographic magnification of the images exists and thus measurements should not be taken directly from these photographs.

The limitations of this study include the use of an animal model. This model allowed control over age, exercise level, diet, and genetic variability. In addition, the porcine cervical spine model has been shown to be anatomically, geometrically, and functionally similar to human lumbar spines[15,16] with similar failure mechanisms. To facilitate radiograph tracking of the nucleus, it was necessary to add 0.55 mL of a radio-opaque mixture to the nucleus of the disc. There was concern that the increase in intradiscal pressure would result in increased frequency of endplate frac-

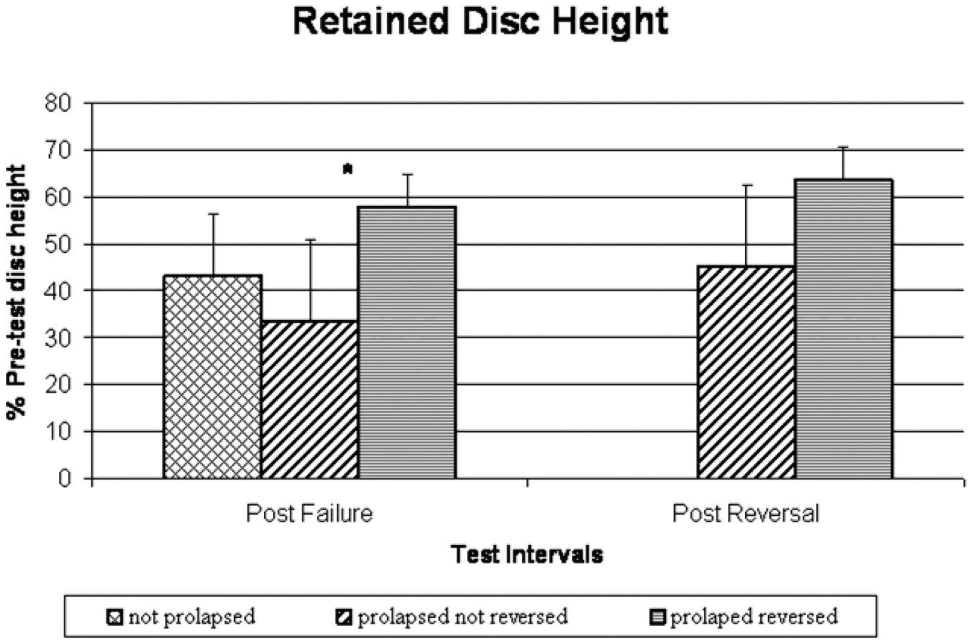

Figure 5. Disc height, measured according to Wilke *et al*,[14] after the failure procedure and after the reversal testing of the three categories of specimens is shown. The specimens that prolapsed and responded to reversal testing had significantly more disc height after the failure procedure then those that did not respond to reversal testing.

ture but this was not found. Concern regarding the separation of the radio-opaque mixture from the nucleus was considered. It is possible that the barium solution did not migrate in concordance with the nucleus but probably not the other way around. We further studied the concordance (unpublished data) between dissection observation, CT scan images, and plane film radiography, which showed that the nucleus could "flow" into clefts of the damaged anulus and the heavier barium-based solution may, or may not follow. However, the opposite was never observed; in other words, if the barium moved so did the nucleus because the nucleus carries the barium. When using a "lighter" contrast solution designed for rapid *in vivo* resorption, perfect concordance was observed between the nucleus and contrast solution "flow" although this medium would not have remained radiologically visible for the length of time necessary for this experiment. Thus, the observations of movement of the barium-based contrast solution used in this study reflect the flow movement of the nucleus. Given the difficulty of interpreting quantified changes in the position of the nucleus, qualitative analysis was the only option available. The independent radiologist's analysis of the radiograph images was from a clinical perspective, that being changes that could have clinical significance.

This study showed that, in a number of spines, a displaced portion of nucleus could be directed back towards the center of the disc in response to particular active and passive movements/positions. This change in position of the tracked nucleus is the mechanism thought to underlie the success of the McKenzie derangement approach in specific individuals. The porcine cervical spine has been shown to be a good geometric, anatomic, and functional surrogate for human lumbar spines. This study sheds light on a theory that has been unsubstantiated in physiotherapy for over 20 years. We propose that the discs in our study that had greater disc height was more likely to reverse as greater extension of the segments could occur before the facet joints bring the range to a halt and also the stress in the posterior anulus was compressive rather than tensile. The increase in stiffness of the specimens, a measure of the damage of the IVD,[17] did not correlate with the disc height loss nor did it distinguish between the categories of specimen behavior. The change in stiffness levels was similar to that reported by Callaghan and McGill[1] and Drake *et al*[18] both of which used comparable models and testing parameters. The increase in stiffness of *in vitro* specimens is usually explained to result from a change in the contact points across the segment associated with a decrease in disc height. However, the displaced portion of the nucleus within the posterior anulus may alter the torque required to rotate the specimen rather than change the contact points. The next questions are whether the returned nucleus material is able to form a plug in the clefts between layers, and splits in the collagen, of the anulus and also what are the optimal extension regimes, in terms of static postures or repeated dynamic motions that assist in returning tracked nucleus.

■ Key Points

- Can extension or combined extension and side flexion move the displaced portion of nucleus toward the center of the disc?
- In 5 of the 11 prolapsed specimens, the displaced portion of the nucleus migrated back toward the center of the disc after the reversal testing.
- The prolapsed discs that centralized had significantly less disc height loss after failure testing.

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