Influence of Disc Degeneration on Endplate Concavity

1Espinoza Orías A A; 1An H S; 1Andersson G B J; +1Inoue N
1Rush University Medical Center, Chicago, IL
+Nozomu_Inoue@rush.edu

INTRODUCTION Most of the direct spinal load transmission is primarily assumed by the intervertebral disc, with the remainder borne by the facet joints. Under ideal conditions, this compressive load is distributed evenly to the annulus fibrosus (AF) as a hoop stress through hydrostatic pressure generated in the nucleus pulposus (NP). When the spine degenerates, the resulting altered mechanical state has been theorized as a load transfer from the nucleus pulposus radially outwards to the annulus fibrosus. Since bone is tissue that adapts continuously to new mechanical loading scenarios, it is postulated that this shift in loading will also affect the geometry of the vertebral endplates.

Therefore, the two purposes of this study were to characterize endplate 3D geometry in vivo, and to assess the effects of disc degeneration on endplate morphometry.

METHODS An IRB-approved protocol allowed CT- and MRI-scanning of 92 volunteers (50M/42F, 37.7±9.8 y.o.) to generate 3D surface models of all inferior/superior lumbar endplates (L1 to L5). A least-distance algorithm written in Visual C++ was used to calculate the disc height-distribution using the inferior endplate of the intervertebral gap as a reference. For each intervertebral gap, the superior endplate of the inferior vertebra corresponding to the caudad side of each disc was used as a reference and subdivided into 4 peripheral anatomical quadrant zones (AF); anterior, posterior, two lateral), and a central zone (NP) contained within an elliptical contour drawn at 60% of the diagonal radius (Figure 1). This NP/AF subdivision ratio correlates to the disc area measurements reported by O’Connell et al. [1]. For each zone a mean gap separation measurement was calculated. These values were used to define endplate concavity scores in the coronal and sagittal planes as: Coronal concavity = Central zone/average of both lateral zones; Sagittal concavity = Central zone/average of anterior and posterior zones, and finally an Overall Concavity = Central zone/Peripheral intervertebral gap. These expressions provide limits with a value of 1 describing a flat surface, a value >1 representing concavity and a value <1 representing convexity. The MRI-based Pfirrmann scale was employed to rate disc degeneration. Results are presented as mean±SEM.

RESULTS Overall concavity scores showed a significant decrease in Grade 4 and 5 discs (Figure 2). Coronal and sagittal concavities with DD grade 5 were significantly lower than those with DD grades 1, 2, 3, and 4. Sagittal concavity with DD grade 4 was significantly lower than that with DD grades 2 and 3 (Figures 3 and 4). Values of concavity with DD grade 5 were less than 1, indicating endplates with DD grade 5 have convex 3D geometry.

DISCUSSION This study showed a decrease in endplate concavity associated with disc degeneration based on 3D data. Our results support the theory of load shift from NP to AF associated with DD by evaluating 3D curvature of endplates. In vivo measurement of the 3D geometry of the endplate may be useful diagnostic method to estimate alternation of load transmission with DD. The intervertebral disc ability and function as a load bearing structure is directly related to the spine structure. The literature shows that disc degeneration produces disc height loss [2], which in turn decreases any other spaces between the spine articulations.

Explanations for such mechanisms for the morphological change seen in these results are lacking in the literature. Based on the results, we propose the following sequence that is related to advancing degeneration: endplates with degenerate discs (grades 2&3) are usually concave; endplates surrounding discs with grade four become essentially flat, with the most degeneration (grade 5) resulting in convex endplates. One potential reason for this is that most of the load at such degeneration grade might be supported peripherally by the remaining annulus fibrosus tissue, since the once healthy nucleus is now essentially deflated due to important decreases in discal hydrostatic pressure.

A limitation of this study is the use of disc height distributions as reference, and not vertebral body contours, such as the results from Shao et al., that were measured on plane radiological images. Contrary to this report, they actually show an increase in sagittal plane concavity [3].

In summary, this study found that endplate morphometry undergoes changes based on biomechanical load alterations that are the consequence of disc degeneration.

Figure 2 Overall concavity scores (unitless) shown by disc degeneration grade. Green lines show statistical differences between disc degeneration grade groups.

Figure 3 Sagittal concavity scores (unitless) shown by disc degeneration grade. Green lines show statistical differences between grade groups.

Figure 4 Coronal concavity scores (unitless) shown by disc degeneration grade. Green lines show statistical differences between grade groups.

SIGNIFICANCE Understanding changes in vertebral morphology with age, degeneration and other more serious spinal diseases are important to the study of spinal biomechanics. In vivo measurement of the endplate geometry may aid to estimate load transmission alterations associated with disc degeneration.

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REFERENCES