

# In-vivo Lumbar Intervertebral Disc Geometric Deformation during Weightbearing Posture

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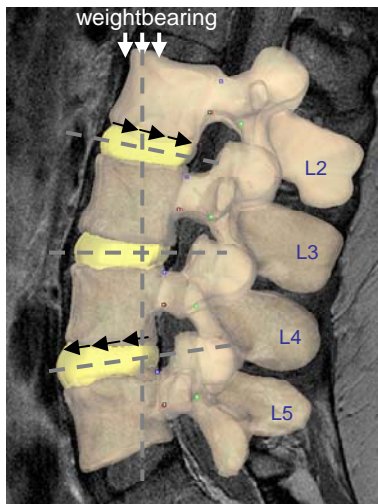
## Introduction

Degeneration of the intervertebral disc is responsible for the vast majority of back pain. Significant efforts have been made to characterize lumbar intervertebral disc (IVD) deformation during physiologic weight-bearing in an attempt at understanding the mechanisms resulting in disc related spinal disorders and improving their surgical treatment. However, the details of IVD deformation, including the magnitude and direction of tension and shear, have yet to be clearly defined in-vivo mainly due to technical limitations. This study investigated lumbar IVD geometric deformation from adjacent level translation and orientation of the endplates using a combined MR and fluoroscopic image matching technique. Tensile and shear deformation was quantified by comparing the weight-bearing (standing) position to non-weightbearing (supine) position at the L2-L5 vertebral levels.

## Method

Eight asymptomatic subjects with an age ranging from 50-60 years were recruited for this study under the authors' institutional review board approval. First, the lumbar segments were scanned using a 3T MR scanner in the supine position and 3D mesh models of the L2-L5 vertebrae were constructed to quantify non-weightbearing vertebral position (Fig 1). Next, two fluoroscopes positioned perpendicular to each other took simultaneous images of the subject standing in the common field of view. The standing posture was carefully examined to ensure the upright position. Using 3D and 2D registration, the MR models were matched to the osseous outlines of the images from the two orthogonal views to quantify vertebral position while weight-bearing [1].

Based on the orientation and translation of the endplates of adjacent levels L2-3, L3-4 and L4-5, deformation-gradient tensor was calculated using the finite-strain theorem [2]. Points were taken from the endplates and tensile deformations were calculated with respect to the disc height (tension/disc height) using the deformation-gradient tensor. Similarly, shear magnitude (translation/disc height) and direction were determined.



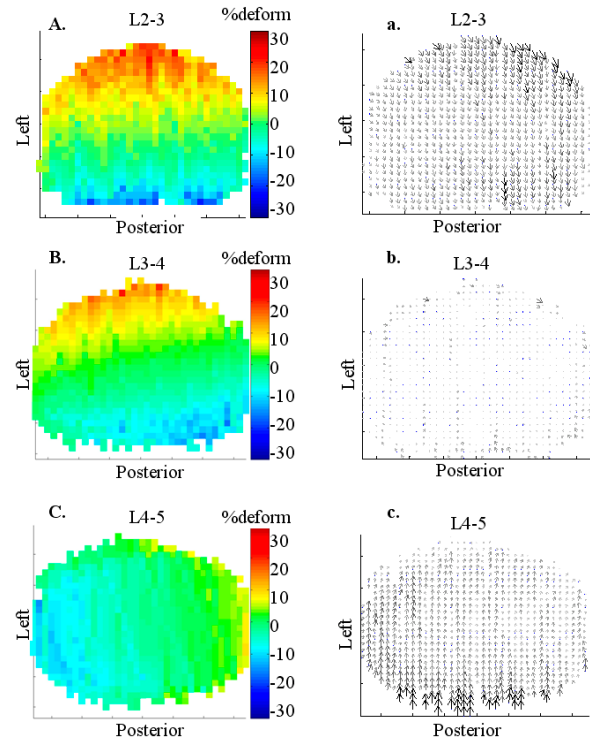
**Fig 1:** 3D model obtained from MRI scan. Arrows show the disc shear direction caused by weightbearing and the lordosis of lumbar spine.

## Result

Similar tensile deformation patterns were found for each patient at corresponding levels. We therefore standardized the patterns according to the size of the disc and mapped them in order to determine the average tensile patterns. Going from non-weightbearing to the standing (weightbearing) position, the anterior third of the L2-3 disc was in tension (+) while the posterior third was in compression (-) (Fig 2). The magnitude change was essentially 'vertical' going from +24% to -21%. L3-4 had a similar conversion; however, the magnitude change occurred from left anterior (+19%) to right posterior (-16%) instead of vertically.

For L4-5, the right portion was under tension (+9%) which gradually changed to compression at the left portion (-14%).

In addition to tensile deformation, we also determined the shear deformation with reference to the two adjacent endplates. With respect to the bottom endplate, L2-3 experienced shear from anterior to posterior with a mean magnitude of 5%-25%. L3-4 experienced minimal shear (<8%) in the diagonal direction, while L4-5 experienced shear from posterior to anterior of 4%-27%.



**Fig 2: A, B, C:** Tension and compression at different disc levels, with color showing percentage deformation. **a, b, c:** Corresponding shear, with arrows showing direction and magnitude.

## Discussion

Disc deformation during weightbearing differed based on the segmental level. The tension and compression portion altered within the vertebral levels. The magnitude of the deformation decreased from the cephalad L2-3 level to the caudad L4-5 level. This may be related to physiologic lordosis and inherent weightbearing patterns of our subjects (for instance; every subject in our study was right-handed). The shear deformation was limited to within 30% (i.e. about 2mm) for each level, which can be attributed to constraint from the strong ligamentous and muscular attachments of the lumbar spine together with the disc material. We also found that L2-3 and L4-5 experienced shear from opposing directions and L3-4 had a small deformation, which can also be attributed to lordosis. Overall the spine maintains stability by balancing shear in different directions and the anatomic inflection point is roughly located at the L3-4 disc (Fig 1).

The IVD plays a critical role in distributing loads equally across the intervertebral body. In the future, data from this study can be used to determine in-vivo 3D stress, strain, and bulging of the IVD using finite element analysis. This data may have implications regarding the patterns of disc disease, such as degeneration and herniation. It is also helpful for improvements in total disc replacements designed for the treatment of various degenerative disc diseases.

## Reference

- [1] Wang S, et al., *Spine*. 2008 May 15;33(11):E355-61.
- [2] Atkin, R J, *Longman Mathematical Texts*. New York, 1980.