MRI method for in vivo modeling of intervertebral discs:
Application to idiopathic scoliosis
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Introduction
Several biomechanical models of intervertebral discs have been proposed (Ueno et al., 1987; Shirazi et al., 1986; Rao et al., 1991; Lavaste et al., 1992; Suwito et al., 1992; Goel et al., 1993; Lim et al., 1994). Geometries were measured in vitro or deduced in vivo from vertebral end-plates. There is no in vivo geometrical data of the interior of the intervertebral disc. MRI is more and more used for etiologic examination of scoliosis and for the intervertebral disc disorder analysis. Clinical parameters were defined on the slices but no geometrical modeling was deduced.

The aim of this study was to develop a new geometric model of intervertebral discs using MRI. Then parameters were defined to quantify the nucleus zone (NZ) migration within scoliotic intervertebral discs. The description should be of interest for further investigations on parameters quantifying the stiffness of the spine.

Methods
Fourteen children having a lumbar idiopathic scoliosis (Cobb angles 22±7°) were examined using MRI. The technical protocol consisted in two acquisitions of the entire spine (turbo spin echo T2-weighted sequence), in the sagittal and frontal plane. The nucleus and the less fibrous part of the annulus gave out a high intensity signal and the most fibrous part of the annulus gave out a low intensity signal. An image processing software (Figure 1) allowed the outline detection of the intervertebral high intensity portion, called the nucleus zone (NZ). Reconstruction of the vertebral bodies was also performed (Périé et al, 2001). Using the pre-post processor Patran (MSC Software), the centroids of each NZ and each vertebral body were computed. Migration of the NZ was deduced. Vertebral rotations were computed. Intervertebral disc wedging was deduced in the coronal plane assuming no wedged vertebrae.

![Figure 1: T2 weighted image of adolescent spine in the coronal plane (a), detection of intervertebral NZ (b)](image)

Results
Repeatability of the measures was obtained (p>0.05), inter-operator (p=0.437) and intra-operator (p=0.6854), with standard deviation of 0.25mm for the NZ migration and 1.2° for the wedging.
A correlation (r²=0.488, p<0.0001) was found between the NZ migration and the disc wedging (Figure 2). The wedging varied from –9 to +6°, the migration from –5 to +7mm. The absolute values of both parameters
were maximum at the curvature apex (L3-L1) and minimum at the curvature ends (L5-L4, T12-T11). When the wedging was positive (left curvature), the NZ migration was negative (left side), i.e. occurred in the convexity of the curvature.

![Graph showing NZ migration as a function of intervertebral wedging.]

**Figure 2**: NZ migration represented as a function of the intervertebral wedging.

**Discussion**
A new geometric model of intervertebral discs had been developed in vivo using MRI in order to assess new parameters describing the interior of the intervertebral disc and its behavior. A correlation was found between the NZ migration and the disc wedging. This obvious result validated the new geometric model of the interior of the intervertebral disc proposed. Moreover, significant correlations were found between nucleus migration and flexion-extension movements of the spine in the sagittal plane using MRI (Fennell et al., 1996; Beattie et al., 1994; Brault et al., 1997). Our results were in agreement with these results: when two vertebrae move deforming the disc, the nucleus moves away from the pinched side of the wedged disc into the curvature convexity.

But should we talk about the nucleus? T2 weighting provides contrast between the most hydrated and the less hydrated portion of the intervertebral disc. Despite image processing software allowing the highlighting of image features (automatic color lookup tables applied to grayscale images using pixel intensity measurements, SigmaScan Pro, Jandel Corp., Chicago, USA), it is impossible to differentiate the nucleus from the annulus on T2 weighted images of adolescent spines. Further development is required in this area.

This new geometrical modeling of intervertebral disc, validated for the quantification of the NZ migration, should be of interest for further investigation on intervertebral behavior and stiffness parameters of spine.

**References**