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Intervertebral disc characterization by elastography: a preliminary study

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1. Introduction

Simulation of the human spine mechanical behavior allows insights on several subjects of study, both in research and clinical application. For instance, it can be used to study growth (Villemure *et al.*, 2002), surgical procedures (Lafage *et al.*, 2004) or scoliosis progression (Drevelle et al., 2010). Reliable simulations require information on the subject-dependent geometry and on the tissues mechanical properties. Thanks to recent technological and technical advances, geometry of the spine can be easily and precisely personalized (Humbert *et al.*, 2009). *In vivo* personalization of the tissues mechanical properties, however, remains a challenge.

Ultrasound elastography has been a subject of research since the early 90s (Ophir *et al.*, 1991), but only recently new quantitative techniques started being introduced in the clinical setting (Tanter *et al.*, 2008). This technique allows the evaluation of the tissue's elastic modulus through the measurement of shear waves' speed of propagation in the tissue; it has been successfully applied to asses several tissues, such as muscles, prostate, liver and breasts.

The hypothesis that was explored in this preliminary study was that intervertebral disc stiffness could be evaluated by elastographic measurements.

2. Methods

Eight intact oxtails were frozen between 1 and 7 days and slowly thawed the day before the test; samples were prepared by isolating the first, second or third caudal segment (two vertebras and the interposed disc) and by removing the soft tissues of the dorsal region. The soft tissues in the ventral region were only partially removed in order to improve the acoustic contact for the elastographic measurements. The cranial and caudal endplates of the segment were then embedded in polymethylmethacrylate (Figure 1), taking care that the vertebral bodies were aligned to minimize buckling during the following compression tests.

Each segment was tested in compression (Instron 5566, Instron, Massachusetts). After applying a 20 N preload, four conditioning cycles between 0 and 400 N at constant displacement speed (0.5 mm/min) were performed; displacement and force, which was measured with a 5kN load cell, were recorded by the testing machine. The force-displacement curve of the fourth cycle was approximated by a multilinear model composed by three line segments; the asymptotic stiffness of the intervertebral disc at 400 N was defined as the slope of the third segment.

Immediately after the fourth cycle, the sample was compressed to 400 N and then the position was held. Ten elastographic images (Aixplorer, SuperSonic Imagine, France) of the intervertebral disc were acquired, with the ultrasonic probe transversally placed on the ventral region of sample, immediately after 400 N were reached. The average shear wave speed in each intervertebral disc was evaluated by averaging the speed values observed in these ten images.

The whole protocol (mechanical test and elastographic measurements) was repeated six times, with 30 minutes pauses, in order to evaluate repeatability. Measurement precision was assessed as described by Gluer *et al.* (2005). Correlations and repeatability were analysed with Spearman's rank correlation coefficient and one-way analysis of variance (ANOVA), respectively; significance was set at 0.01.

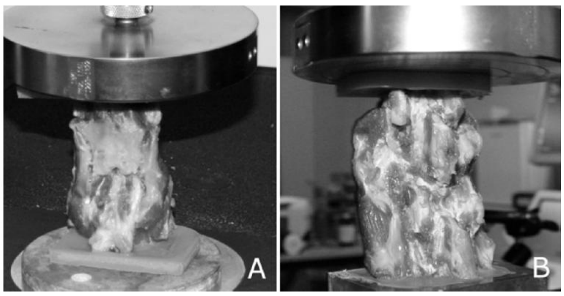

Figure 1 Preparation of a sample; soft tissues of the ventral region (A) were left intact while they were removed in the dorsal region (B). PMMA plates are visible at the segment ends.

3. Results and Discussion

Eight tests out of 48 total (8 samples times 6 repetitions) had to be discarded because of artefacts observed in the elastographic images.

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These artefacts were often due the coccygeal artery, a large blood vessel that runs longitudinally in the ventral part of the oxtail where the elastographic measurements were performed; the absence of blood might have allowed presence of small air pouches in the empty artery, thus affecting ultrasound propagation.

Average intervertebral disc stiffness was 731.6 ± 104.0 N/mm (mean ± SD, ranging from 487.6 to 897 N/mm). Precision of stiffness measurement was 39 N/mm (5 % coefficient of variation).

Average shear wave speed was 4.9 ± 1.1 m/s (ranging from 2.4 to 8.0 m/s), and the measurements of each sample were repeatable ($p > 0.01$, ANOVA). Precision of shear wave speed measurement was 0.6 m/s (12.4 % coefficient of variation). Pooled data ($n = 40$) showed a significant correlation between intervertebral disc stiffness and shear wave speed (Spearman's rho = 0.45, $p = 0.002$, Figure 2). A tendency, although not significant, was also observed for average values (Figure 2).

The poor correlation of average values was probably due to two main factors: first, the number of measured samples was low (more experiments are currently being performed). Second, shear wave speed was compared to the intervertebral disc stiffness; the former depends on the tissue's shear coefficient which, with the hypothesis of isotropy and homogeneity, is related to the tissue's elastic modulus (Royer *et al.*, 2011). The latter depends on the whole sample structure and, although it is probably correlated to the disc's elastic modulus, it does not directly affect shear wave speed.

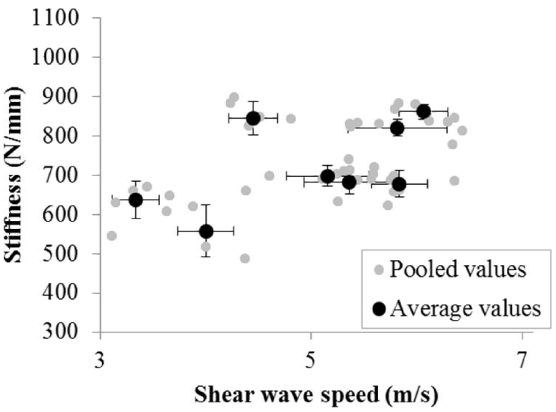

Figure 2 Intervertebral disc stiffness versus shear wave speed; pooled values (light grey dots, Spearman's rho = 0.45, $p = 0.02$) and average values (black dots with error bars representing the standard deviations, correlation not significant).

The correlation might improve by comparing shear wave speed to the disc's apparent elastic modulus in compression, which can be evaluated from stress-strain curves. Stereoradiographic images of the samples are currently being acquired in order to measure the discs' thickness (Rillardon *et al.*, 2005) and cross-sectional area, which will allow the evaluation of stress and strain.

4. Conclusions

In this preliminary study, a correlation was observed between intervertebral disc stiffness and the shear wave speed measured by elastography. Although these results have to be confirmed on more specimens and refined by measuring material properties, they are encouraging on the feasibility of non-invasive intervertebral disc mechanical assessment by elastography.

Acknowledgments

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