ANISOTROPY OF THE HUMAN VERTEBRAL BODY SUB-STRUCTURES EVALUATED WITH MICRO-INDENTATION

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Introduction

Experimental data about the mechanical properties of the different sub-structures of the vertebral body are necessary to improve computational modelling of the spine. Micro-indentation can be used to investigate the mechanical properties and bone anisotropy at the tissue level. However, only a few studies have investigated, the anisotropy of cortical and trabecular bone at such scale [Roy, 1999; Wolfram, 2010]. Moreover, little is known about the mechanical properties of osteophytes, calcifications of the vertebrae that affect the spine mechanics of most elderly patients. The goal of this study was to quantify and compare the indentation properties of the different sub-structures of the human vertebra (endplates, shell, trabecular centrum and osteophytes) by means of instrumented indentation along different directions.

Methods

Six vertebral bodies were collected from subjects without bone diseases. Eleven sub-samples were cut from each vertebra to perform indentations on the cortical shell (along axial, circumferential and radial directions), on the cortical endplates (along the anterior-posterior and lateral directions) and on the trabecular centrum (along the axial and transverse directions of trabeculae). Moreover, five vertebrae with osteophytes were collected. From each one, a portion of the largest osteophyte was isolated and indented along the axial direction. Each sample was cleaned from soft tissues, embedded in epoxy resin and polished. Indentations were performed in dry conditions, with a Berkovich tip, in load control (60 mN/s) down to a maximum depth of 2.5 µm. If the load-displacement curve did not show any contact problem, the Oliver&Pharr method [Oliver, 1992] was used to compute the indentation modulus Ei.

Results

A total of 3058 valid indentations were performed on the cortical shell (1816), endplates (415), trabecular region (377) and osteophytes (450). The cortical shell was found to be significantly stiffer along the axial direction (14.6±2.8 GPa) compared to the circumferential (+16%) and radial (+43%) directions. The trabecular tissue was found to be stiffer along the axial direction (13.7±3.4 GPa) compared to the transverse one (+21%). The endplate showed small differences (8%) between indentations along the lateral and anterior-posterior directions. Osteophytes showed to be in average less stiff than the other substructures (10.5±3.3 GPa) (Figure 1).

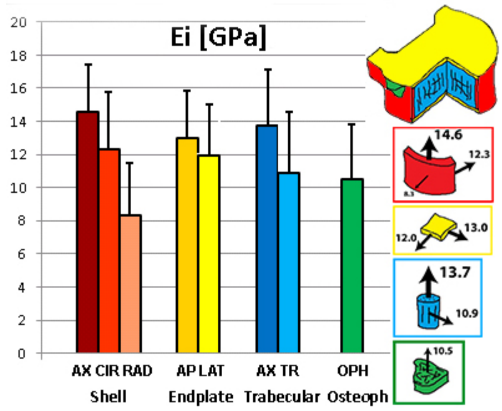

Figure 1: Average and standard deviations (error bars) for the indentation modulus Ei split for different sub-structures and indentation directions.

Discussion

The cortical shell showed an orthotropic behaviour, and both trabecular centrum and cortical endplates a transverse isotropic one. Osteophytes showed low Ei compared to the other sub-structures, suggesting that they are not as stiff as healthy bone. These results will be helpful for the definition of the material properties in computational models (such as finite element analysis) of the human vertebral body.

References

Roy *et al*, JBiomedMaterRes, 44:191-7, 1999

Wolfram *et al*, Bone, 46: 348-54, 2010

Oliver and Pharr, JMaterRes, 7:1564-83, 1992