EFFECTS OF INTERVERTEBRAL DISC DEGENERATION ON THE STRAIN DISTRIBUTION ON THE DISC SURFACE

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Introduction

Intervertebral discs (IVDs) degeneration is defined as "*structural failure combined with accelerated or advanced signs of ageing"* [1]. Indeed, it implies a tissue weakening primarily due to genetic inheritance, aging, nutritional compromise, and loading history. The structural disruption occurring from injury or fatigue loads leads to the hypothesis that degenerated IVDs are subject to larger deformations.

The effects of the IVDs degeneration can be evaluated experimentally by combining mechanical tests and Digital Image Correlation (DIC) to measure the strain field on the surface of the IVDs.

The aim of this study is to evaluate the strain distribution on the IVDs before and after a mechanically induced IVDs degeneration.

Materials and Methods

Four T9-L1 human spine segments were obtained through an ethically approved donation program (Ethical approval: Prot.n.113043).

Each specimen was scanned with a 3T Magnetic Resonance Imaging (MRI) and a Computed Tomography (CT) to establish the initial degeneration of the IVDs (Pfirrmann grade = 2 in all specimens) [2] and exclude critical bone pathology. All soft tissues and the anterior ligament were removed without damaging the IVDs. A high-contrast white speckle pattern was prepared on the surface of each specimen.

A four-cameras 3D-DIC system (Aramis Adjustable 12M, GOM) was used to measure the surface strain field on the IVDs, at 25 frames per second, with a pixel size of 0.07mm. Mechanical tests were performed using a uniaxial testing machine (Instron 8500, 10kN load cell) to induce flexion, right and left lateral bending, and compression, as defined by [3], on the intact specimens. Each spine segment was loaded until the average minimum principal strain on the central vertebra reached approximately $3000\mu\varepsilon$ (target to remain in elastic regime without damaging the bone). Ten preconditioning cycles up to half of the load corresponding to the target strain were applied. Then, each specimen was loaded monotonically to reach the target strain in 1s. Artificial IVDs degeneration was mechanically induced (nucleoctomy) [4] to simulate a Pfirrmann grade 5 of degeneration [2] in the T11-T12 IVD. Then the degenerated specimens were tested again, following the same loading protocol.

DIC precision was evaluated as the standard deviation of the strain (random error) in zero-strain condition. The minimum principal strains (Eps3) were measured and compared before (intact condition) and after (degenerated condition) the IVD degeneration.

Results

Random errors were smaller than $100\mu\varepsilon$. The Eps3 were larger after IVDs degeneration (Fig.1). In particular, the Eps3 increased by 43% and 57%, in the non-degenerated disc and in the degenerated disc, respectively. 3D strain colour maps allowed to identify the IVD regions which experienced the larger strains. While in the non-degenerated condition the strain distribution was rather uniform, regions with strain concentrations appeared after IVD degeneration (Fig.1).

Discussion

IVD degeneration leads to an increase in the strains in the degenerated IVD. Due to the change in the load sharing in the spine segment after the degeneration, the non-degenerated IVD experienced larger strain in most cases. Further analyses and mechanical tests are still on going to enlarge the sample to generalize the findings and to extend the analyses on the effects of IVDs degeneration on the adjacent vertebrae.

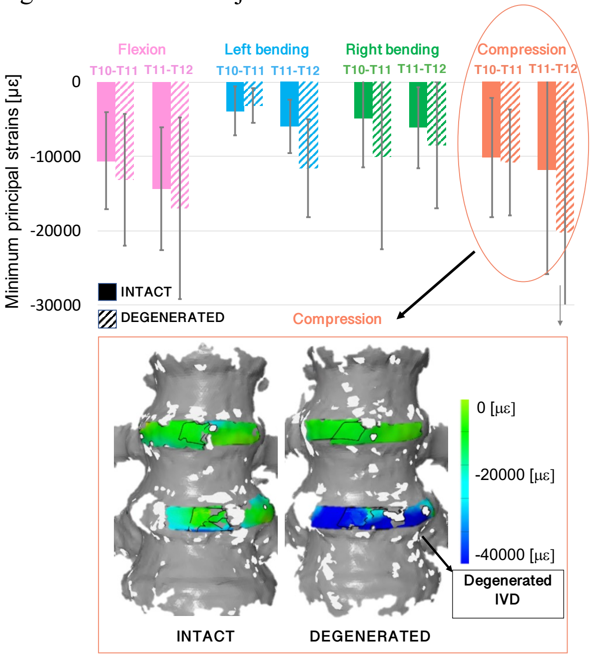

Figure 1: Top: Eps3 averaged on the IVDs surface for each loading condition (median and SD among the sample). Bottom: 3D-strain colour map of the Eps3 on the IVDs surface before and after IVD degeneration.

References

1. Adams et al. (2006), Spine. 2. Pfirrmann et al. (2001), Spine 3. Palanca et al. (2021), Bone. 4. Techens et al. (2020), MEP

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