Intervertebral Disc Degeneration can induce Degenerative Bone Adaptation in Adjacent Vertebrae

INTRODUCTION

Vertebral fractures are associated with height loss, acute and chronic back pain, disability, reduced quality of life and even increased mortality rates\(^1\). As the prevalence of vertebral fractures rises dramatically with age they pose a large problem for the elderly\(^2\). While these fractures are conventionally attributed to osteoporosis, a recent study has found that disc degeneration also leads to an increased vertebral fracture risk\(^3\). Although a correlation between disc degeneration and a changed bone density distribution in the vertebra has been found\(^4,5\), the exact path to the increased fracture risk remains unclear.

Disc degeneration typically results in a dehydrated and fibrous nucleus, no clear distinction between the annulus and the nucleus, a disorganized arrangement of annular fibers and a decreased disc height. The degenerative process seems to typically start in the nucleus followed by the annulus\(^6,7\). Disc degeneration undeniably changes the load on the adjacent vertebrae which has been suggested to lead to bone adaptation resulting in an increased fracture risk\(^8\).

In this study we developed, validated and used a sophisticated biomechanical model, capable of simulation bone adaptation, to:

1. assess whether bone density changes, as seen in aging spines, can indeed be explained by disc degeneration
2. assess which of the aspects of disc degeneration is most detrimental

METHODS

We obtained an L2-L4 segment from an 81 year old female cadaver. All soft tissues (except spinal ligaments) were removed from the spine segment and four metal pallets were inserted into each of the three vertebrae to allow for RSA measurements of the deformations. Density calibrated CT-scans were made at a resolution of 0.3x0.3x1mm.

For validation purposes, the bending stiﬀness of the segment was measured in flexion, extension, lateral bending (left and right) and torsion (left and right). The endplates of the spine segment were embedded in PMMA-cement and fixated in a custom made testing jig. The specimen was preloaded for one hour with an axial load of 50% of the estimated bodyweight to eliminate overhydration of the discs. The specimen was then loaded instantaneously with 5Nm and RSA-measurements were taken just before and just after applying the load to quantify the kinematics of the individual motion segments.

Based on the CT-data we constructed an FE-model of the spine segment (figure 1). The stiffness of the bone elements was based on their apparent density values\(^7\). Poisson’s ratios for all bone elements were set at 0.3. Facet joints were modeled using contact elements. As the intervertebral discs could not be extracted from the CT-data they were constructed based on literature data, including a nucleus and an annulus\(^8\). Initial properties of ligament and facet joint capsules were based on literature\(^7\), but were calibrated by fitting the models kinematic behavior to the RSA measurements (figure 2).

RESULTS

Our simulations show that disc degeneration results in a large reduction of apparent density in the vertebral core. Both the anterior and posterior wall saw an increase in density (resp. 12% and 10%), while the lateral walls showed little change (2%). Disc degeneration step 2 decreased the density of the core even further (-65%), but did not seem to have much of an additional effect on the anterior, posterior or lateral wall (figure 3).

There are two main limitations of this study. First, we did not model the running of discs seen in disc degeneration, our discs were rather thin. We thus only studied effects of changes in material properties. As the dehydration of the nucleus precedes the loss in disc height\(^6,8\), this should not change our conclusions. Second, aging also affects ligaments, muscles and bone adaptation itself, which can all potentially influence bone adaptation in the vertebral body and thus require further study. It may, for example, be that while younger vertebral can adapt in synchronization with the process of disc degeneration and its resulting load shift, older vertebral cannot and are more likely to fracture.

In conclusion we found that disc degeneration can induce a density decrease in the trabecular core and a density increase in the anterior and posterior walls. These changes are mainly caused by the dehydration of the nucleus. These findings may change the way we look at prosthetic discs that are aimed to restore the kinematics without considering the loading mechanics. Such discs may fail on the longer term due to adverse bone adaptation processes in adjacent vertebrae.

REFERENCES