INTRA AND INTER OPERATOR VARIABILITY IN A FINITE ELEMENT MODEL OF VERTEBRA FOR FAILURE LOAD PREDICTION

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Introduction

Vertebral fractures are frequent with the decrease of bone density due to age [1]. Finite element (FE) models of single vertebrae, based on QCT imaging, have been proposed to estimate failure load [2, 3], but their reproducibility needs to be assessed before considering a clinical application [4]. Vertebra segmentation is a critical step for the model construction, because it is partially done manually and is potentially operator dependent. The aim of this study was to assess the intra- and inter- operator variability of a previously developed a finite element model of vertebra for failure load prediction [5]. It was hypothesized that the level of expertise of the operator, as well as scan resolution, would affect the reproducibility of the segmentation and, therefore, the predicted failure load.

Materials and methods

21 intact L3 vertebrae were scanned using a HRp-QCT device (XtremeCT, Scanco Medical AG, voxel size: 82 µm) with a calibration phantom (Mindway). To assess intra-operator variability, one experienced operator manually segmented vertebral bodies (3D slicer) twice from the scans resampled to 0.984 mm and 0.328 mm. To assess inter-operator variability, two additional operators with different levels of expertise (competent and beginner) performed segmentations from the aforementioned scans. FE analysis was then performed automatically as follows. Segmented vertebrae were meshed using 1 mm^3 quadratic tetrahedron elements (Ansys 2019 R1). Each element was assigned a Young's modulus, E, based on its density, ρ_{QCT}, using the relationship $E(MPa) = 3230\rho_{QCT}(g/cm^3) - 34.7$ [6], with a material step of 10 MPa. Perfect plasticity was given to each element once they reached 0.7% yield strain. Vertebrae were compressed to reach a total strain of 1.9%, defined as the failure criteria [7]. For each vertebra and scan resolution, the relative difference between the failure loads obtained by the experienced operator after the first and second trials was calculated (intra-operator variability). The relative differences between the failure loads obtained by (i) the competent or beginner operator and (ii) the experienced operator (first trial) was calculated (inter-operator variability).

Results

Intra-operator variability was low at both voxel sizes, with an absolute relative difference on the failure load of 1.8±1.8% for 328 µm, and 3.6±2.7% for 984 µm (Figure 1). A finer scan resolution significantly (p=0.02) improved intra-operator reproducibility, which can be explained by an easier delineation of bone boundaries. Similar results were obtained for inter-operator variability in the failure load between competent and experienced operators. Inter-operator variability increased for a voxel size of 328 µm when the operator was a beginner compared to a competent operator, with an absolute relative difference on the failure load of 5.8±7.2% and some values above 15%. Notably, inter-operator variability was similar at both scan resolutions for the beginner operator.

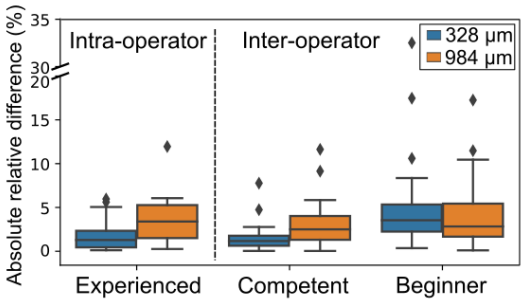

Figure 1: Intra- and inter-operator relative difference on the failure load according to level of expertise of the operator and voxel size.

Discussion and conclusion

Although intra- and inter- operator variability of failure load prediction due to segmentation is low, it should be considered when assessing the accuracy of FE models, especially for a clinical application where scan resolution is coarser (voxel size ≈ 1 mm). Moreover, a minimum experience with vertebra segmentation is required to get more reproducible results, motivating the development of automatic segmentation methods.

References

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