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# COMPARISON OF SINGLE VERTEBRA MODELS INCLUDING ENDPLATES FOR FAILURE LOAD ESTIMATION

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## Introduction

Vertebral fractures are frequent especially with rising age due to loss of bone density [1]. Voxel-based models of bone failure have been proposed to estimate failure load of single vertebrae including vertebral endplates [2], but there is no international standard for these Finite Element (FE) models. One methodology, based on non-linear voxel FE model, is known to show good results in predicting incident vertebral fractures [3]. The aim of this study is to compare our tetrahedral models to voxel-based models found in literature [4, 5, 6].

## Material and Methods

Ten L3 vertebrae without posterior arch (4 females, 6 males,  $74.5 \pm 8.2$  y.o.) were compressed until failure as described in [7]. Image acquisitions before failure were performed using a HR-pQCT device (High-Resolution peripheral Quantitative Computed Tomography, XtremeCT, Scanco Medical AG, Bassersdorf, Switzerland,) with a voxel size of  $82 \mu\text{m}$ .

For our model, two types of mesh were created: an isotropic voxel mesh of  $0.984 \text{ mm}^3$  size and a quadratic tetrahedrons mesh. A hydroxyapatite phantom was used to calibrate grey levels into bone densities. Average grey levels for each element were assigned with a custom script for the voxel meshes and using Bonemat (Bonemat v3.2, Bonemat software, Bologna, Italy) for the quadratic tetrahedral meshes. Then the same law as proposed in [8] was used to attribute Young's modulus and yield strength. The plastic modulus was set to 1 MPa for all elements. Each vertebra was then compressed to reach a total deformation of 1.9% according to failure criteria in [6]. Non-linear finite element analysis was performed with ANSYS (v19R2; Swanson Analysis, Houston, PA).

## Results and Discussion

Differences between simulated and experimental failure loads for our tetrahedral and voxel models are not significantly different (Wilcoxon-Mann Whitney test, p-value = 0.65). There are no significant differences between failure loads computed using our quadratic tetrahedral and voxel meshes (Wilcoxon signed rank test, p-value = 0.49). Our models are similar to the literature in terms of mean difference and Standard Deviation (SD) between numerical and experimental failure load (Table 1).

Studies	Mesh	N	$F_{num}-F_{exp}$ (N)
Current study	Tetrahedron	10	$-179 \pm 938$
	Voxel	10	$43.7 \pm 967$
Chevalier et al. [4]	Tetrahedron	12	$1829 \pm 1141$
	Voxel	12	$1631 \pm 1061$
Buckley et al. [5]	Voxel	17	$68.3 \pm 677$
Wang et al. [6]	Voxel	52	$-492 \pm 880$

Table 1: Differences between numerical and experimental failure loads ( $F_{num}-F_{exp}$ ), mean  $\pm$  SD

Non-linear voxel-based models [4, 5, 6] also add thin layers of polymethyl-methacrylate over endplates to transmit loads which was not reproduced in the current models. This may have an effect on the results. Various bone densities - mechanical properties relationships were found in the literature (e.g. [4, 5, 6]). The choice of this relationship should be included in a future standard. After conversion of the grey levels, the mechanical properties attribution to elements has not been depicted in literature which could induce uncertainties [9].

## Conclusion

As there are no significant differences between our quadratic tetrahedral and voxel model in a non-linear analysis, we could keep either one of them for the simulation of vertebral failure load. The selection between the two meshes could be made according to the automation and the reproducibility of the process which are key factors to transfer these simulations to clinical applications. Even if the simulations performed in the current study and in the literature were performed in different laboratories and are consistent, international standard would improve reproducibility and should be defined for application in clinical settings.

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