PATIENT-SPECIFIC SPINAL BONE SCREW FIXATION: HOMOGENIZED VERSUS VOXEL-BASED FINITE ELEMENT ANALYSIS

Einafshar, Mohammadjavad; Rouyin, Alireza ; Rajairad, Mohadeseh ; Salmani, Mohammadjavad ; Farahmand, Farzam; Arjmand, Navid

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PATIENT-SPECIFIC SPINAL BONE SCREW FIXATION: HOMOGENIZED VERSUS VOXEL-BASED FINITE ELEMENT ANALYSIS

Mohammadjavad Einafshar[1,*] Alireza Rouyin[2], Mohadese Rajairad[3], Mohammadjavad Salmani[2], Farzam Farahmand[2], Navid Arjmand[2]

1. Department of Material and Production, Aalborg University, Aalborg, Denmark
2. Department of Mechanical Engineering, Sharif University of Technology, Tehran, Iran
3. Department of Biomedical Engineering, university of Isfahan, Isfahan, Iran

INTRODUCTION

Bone screws are vital for orthopedic procedures but often lead to issues like dislocation and bone problems. Current testing with cadaver bones is slow and lacks consistency [1,2]. Computer simulations provide a faster, cost-effective way to assess screw designs and reduce the need for human samples. Numerical models consider factors like geometry and materials but struggle with bone variability [3]. Micro finite element analysis shows promise but needs to accurately represent non-linear effects and the bone-screw interface. Few studies have compared numerical models to mechanical tests, especially concerning stiffness and strength [4]. This study aims to quantify pull-out characteristics of bone screw in both homogenized and non-homogenized material.

METHODS

The finite element (FE) model was created using CT images of two 23–26-year-old volunteers without a history of low back disease. The bone segmentation was performed using Mimics software, and posterior elements were removed with 3-Matic software (Fig. 1.A). Each vertebra had a 30 mm long, 5.5 mm diameter, and 2.5 mm pitch screw inserted with a 0.05 mm gap. The screw paths followed the oblique lumbar interbody fusion (OLIF) approach. Material properties were assigned to each vertebra based on voxel-based or homogeneous modeling. Voxel-based modeling considered material heterogeneity, while homogeneous modeling used the average Hounsfield value of a two-fold-diameter of the screw as the material reference volume (Fig. 1.C). Relationships were used to convert Hounsfield values to mechanical properties. Cortical bone voxels with Hounsfield values greater than 500 HU were modeled homogeneously. The thin shell of the vertebral body had a negligible impact on results. Interface modeling employed a general contact model with a tangential friction coefficient of 0.2 and hard contact conditions between screw threads and the threaded hole in the vertebra. Boundary conditions involved clamps at the anterior and posterior shell of the vertebral body (Fig. 1.B). A 0.25-mm displacement along the screw's longitudinal direction simulated pull-out.

RESULTS AND DISCUSSION

A total of 20 pull-out tests were simulated using and the obtained pull-out forces ranged from 652 to 1424 newtons. The pull-out displacement ranging from 0.188 to 0.21 mm. The pull-out stiffness varied from 6792 to 14402 N/mm (Table 2), and the pull-out strain energy ranged from 58 to 91 N.mm (Table 4). Furthermore, the stress contour was shown in three states: the first simulation, maximum force, and after damage (Table 1). The relationships between the forces and the stiffnesses and their errors in the two cases of voxel-based and homogeneous in the different standard deviations of material reference volume are reported in the graphs.

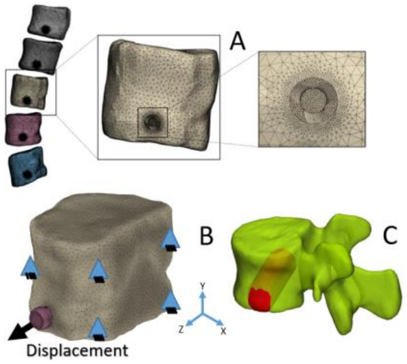

Fig. 1. A) 3D model fabrication, B) Boundary Conditions and C) two-fold-diameter material reference volume.

CONCLUSIONS

The present study introduces a novel methodology for conducting investigations on cancellous bone with homogenous modeling. Prior to this research, the only viable approach was to employ heterogenous models. By leveraging the findings of this study, it is now feasible to replicate the authentic conditions of cancellous bone in a patient-specific pull-out test on a block.

Table 1. Voxel-based and homogenous force calculation. The Force errors were also calculated between two models.

Vertebra	Hu	Force (N)		Error
		Voxel-based	Homogenous	(%)
L1	84	952.8	977	9.7
L2	88	990.3	1021.8	4.3
L3	88	1065.2	1041.6	3.8
L4	125	1305.9	1070.8	10.1
L5	105	1165.7	1049.6	16.4
L1	58	994.9	1257.4	21.8
L2	57	1391.4	1401.8	4.8
L3	61	1408.9	1424.3	9.1
L4	63	1155.1	1224.7	5.4
L5	76	1155.2	1269.8	6.7

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