

# Robustness to Inclination of CT Based Vertebral Finite Element Models Obtained with Reduced Exposure

Camryn Keller, Ross Dies, Andrew Zhang, Alberto Simoncini, Phillip Fincher, Daniel Hayward, Milan Mody, and Giovanni F. Solitro  
Louisiana State University Health Sciences Center at Shreveport  
giovanni.solitro@lsuhs.edu

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**INTRODUCTION:** Vertebral compression fractures (VCFs) are common with approximately 1.5 million cases being reported each year in the United States. The risk of compression fracture increases with age. Women are at increased risk due to greater prevalence of osteoporosis and increased fall incidence. Biannual screening in women over the age of 65 and men over the age of 70 is recommended and the standard preventative screening for bone mineral density (BMD) is dual energy X-ray absorptiometry (DXA). The assessment of vertebral BMD with this technology has a sensitivity of 59% and 46% for women and men, respectively. However, it cannot be performed on individual vertebrae or on vertebrae with a rib overlying it. A viable alternative to DXA screening is Finite element analysis (FEA), which is based on quantitative computer tomography (qCT), and has been used to predict fracture risk. Because FEA exposes the patient to large doses of radiation, CT scanning may be limited to the middle portion of the vertebral body for vertebral mechanical characterization, which has been previously proposed in an animal model. The current study aims to evaluate the sensitivity of the imaging direction and scanning thickness on the vertebral body mechanical characterization through FEA in human vertebrae. We hypothesize that there is a threshold in vertebral rotation and thickness of the scanning for which the estimated mechanical characterization remains reliable.

**METHODS:** The study was performed in two separate phases. In the first phase, we performed imaging, reconstruction, and finite element modeling of T7 and T12 vertebrae harvested from 19 cadaveric spines with age of  $78.5 \pm 6.7$  (53% males, 47% females). Computed tomography (CT) scans were performed using a LightSpeed VCT scanner (GE HealthCare Technologies Inc., Chicago, IL) at a slice thickness of 0.625mm. CT densitometric calibration was performed using a QCT Calibration Phantom (Mindways Inc., Austin, TX). Following the scanning, Slicer3d (www.slicer.org) was used to reconstruct the vertebrae using threshold and manual tracing. Following reconstruction, an algorithm was custom made in Rhinoceros 3D (Robert McNeel & Associates, Seattle, WA) to section each vertebra at 20, 25, and 30% thickness and at inclinations ranging from -10 to +10 degrees in 5 deg increments. The obtained meshes were then imported in Bonemat (Istituto Ortopedico Rizzoli, Bologna, Italy) and paired with the acquired CT scan to assign the material properties following a previously published procedure. The characterized meshes were then exported in Abaqus to simulate compression. The entire vertebrae were simulated constraining all degree of freedoms (DOF) of the inferior endplate and imposing a 1mm axial displacement to the superior endplate while leaving free the DOFs in the other two directions. Similar conditions were used for the vertebral slices for which the amplitude of the axial displacement was limited to 1% of the slice thickness. The cadaveric vertebrae were tested with the inferior endplate rigidly connected to the frame of the mechanical testing machine Instron 8872 (Instron Corp, Canton, MA), while the superior endplate was displaced at 5mm/min until failure executed recording load-displacement data at 100 Hz and every 1N increment (see Figure 1). Stiffness was evaluated as the slope of the obtained load-displacement curve. Pearson product-moment correlation coefficient was used to evaluate the agreement of the computer model with the cadaveric testing and to probe the relationship between the mechanical characteristics extracted from the slices and the entire vertebrae.

**RESULTS SECTION:** For all the cadaveric vertebrae tested, we found a stiffness of  $6908 \text{ N/mm} \pm 2352$  and was strongly correlated to the values obtained from the respective FE models ( $r=0.76$ ,  $p<0.01$ , see Figure 2). The values of stiffness measured for the slices were not influenced by the slice thickness ( $p>0.05$ ) neither by the angle of the slice inclination ( $p>0.05$ , see Figure 3).

**DISCUSSION:** The results found in the study indicate that CT scanning of the middle portion of the vertebrae to estimate vertebral stiffness is robust in relation to thickness and inclination. In the study current study, we considered a smallest thickness of 20% and the highest inclination of 10deg and for the 24 vertebrae studies, we obtained a total of 144 FE models. Additional inclinations and thicknesses still need to be investigated.

**SIGNIFICANCE/CLINICAL RELEVANCE:** Robustness of the approach is essential in the use of a screening technique for patients at risk of vertebral compression fracture. The data found indicates the potential to estimate vertebral stiffness while limiting exposure to ionizing radiations.

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Figure 1: Experimental setup used for compressing the cadaveric vertebrae.

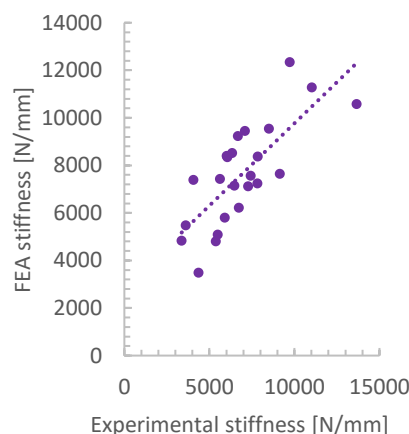


Figure 2: Identified relationship between experimentally and FE evaluated stiffnesses.

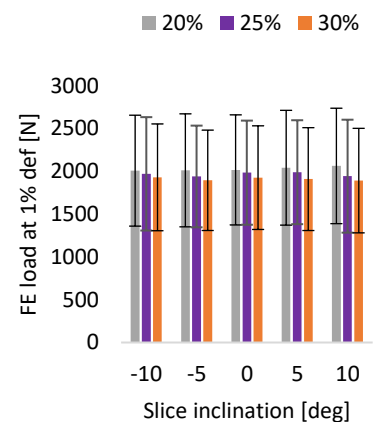


Figure 3: Values of FE estimated loads at 1% deformation in relation to slice thickness and inclination.