MIMICING LUMBAR VERTEBRAL BONE ARCHITECHTURE USING LAYERED MANUFACTORING TECHONLOGY

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ABSTRACT

An experimental model of vertebral bone was investigated in which biological factors were removed. Using layered manufacturing called Fused Deposition Modeling (FDM) and CAD software (Pro-Engineer), trabecular core as well as the vertebral shell was created. The porosity and orientation of the core is computer controlled. Different samples of 25mm cubes of trabecule were fabricated as well as samples of vertebral bodies with porosities of 84% and 92%. Uniaxial compression tests were preformed using a materials testing machine. Load-Displacement curves were analyzed and compared to cadaver data. The specimens tested exhibited behavior close to that of lumbar specimens of cadavers when the plasticity parameters were compared. This would imply that the experimental model provides a good tool to investigate the effect of trabecular bone architecture and age related alteration on load capacity.

INTRODUCTION

The vertebral bone is a geometrically complex structure that consists of a thick shell, soft core of trabecular bone and thin cortical plates on the top and bottom of the body. As age increases the bony material that is constantly recycled is absorbed more than deposited [2]. The result leads to osteoporosis, a skeletal disease characterized by low bone mass and deterioration of bone tissue [3]. In the spine, acute back pain, spinal cord compression, loss of mobility and height result from the disease [3]. Often compressive fractures occur under normal loading conditions because of the thinning of the vertebral body. This makes the vertebral body susceptible to more fractures. Characterization of the shell thickness and the trabecular core are difficult because of biological factors such as age and sex. The focus of this study is to understand the compressive behavior of the vertebral body through FDM models with different biological factors. These factors are easily altered to model a wide range of vertebral bodies, which play a vital role in understanding the reaction of the body to compressive loading conditions.

METHODS

A vertebral body of an average size L3 vertebra was created in Pro-Engineer and manufactured using an FDM 3000 unit. The cortical shell thickness was 1mm. Inner trabecular core was fabricated with a random orientation. The angle of trabecule in a layer was created by generating a random number in Matlab. Each trabecule was 0.3mm in diameter. The age related effect was introduced by creating the porosity of 84% and 92%, by altering the distance between each trabecule. 25mm cubes with no walls were created with different distances between trabecule to determine porosity, Figure 1.

Figure 1: FDM model of the trabecular core

Porosities were calculated by dividing the difference between model volume and total volume with the total volume. 25mm cubes of trabecule were also fabricated to quantify the core load deflection behavior. These samples were subjected to compressive loads by using a plunger that isolated the trabecule. In addition to the vertebral bodies, 25mm cubes and cubes of trabecule, vertebral bodies with 1mm cortical end plates with 2 holes on the top end plate were fabricated. These models were filled with water and the holes were sealed with rubber cement. All of the samples were subjected to uniaxial compression tests at a rate of 5.08mm/sec.

RESULTS

The relationship between porosity and trabecule distance can be seen in **Figure 2.** The air gap distance between the successive trabecule for a porosity of 92% was found to be 5.08mm and for 84% porosity trabecule distance was 1.715mm. These distances between trabecule were used in the vertebral body model as well as the cubes of trabecule. The porosity was nonlinearly related to air gap and linearly related to the trabecule diameter paramter. The stiffness of the 25mm cube the stiffness was found to be 4.11 N/mm and 20.1 N/mm for the 92% and 84% porosity respectively.

The compressive load deflection behavior for the vertebral bone models are shown in **Figures 3 and 4**. For 92% porosity L3 samples, the average first maximum load was 1958 N, which stabilized to 1335 N. For 84% Porosity L3 samples, the average first maximum load was 2942 N, which stabilized to 2134N. The shapes of the vertebral bone load-deflection curves were similar to the cadaver vertebral bones.

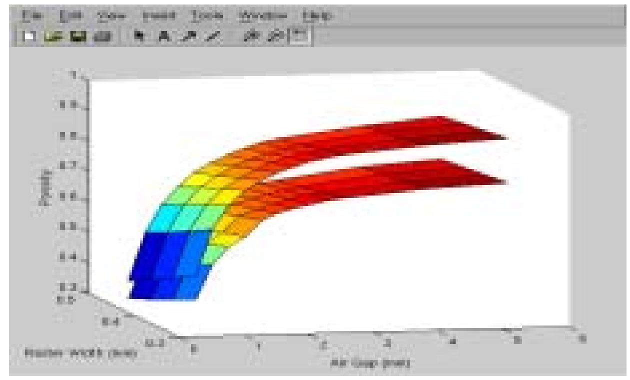

Figure 2: Porosity in a core wrt trabeucle diameter and air gap

DISCUSSION

In a parallel spine biomechanics study in our laboratory, several cadaver lumbar vertebral bones were tested in compression load [1]. The shapes of the vertebral bone load-deflection curves were similar to the cadaver vertebral bones. In that investigation, the average maximum load to failure of a human cadaver lumbar vertebral bone was found to be 4500N. This value is 3.37 times larger than the FDM model. But the modulus of vertebral lumbar bone was calculated to be 5-7Gpa compared to 2.48Gpa for the FDM material. The fabricated material is almost three times weaker than the vertebral bone.

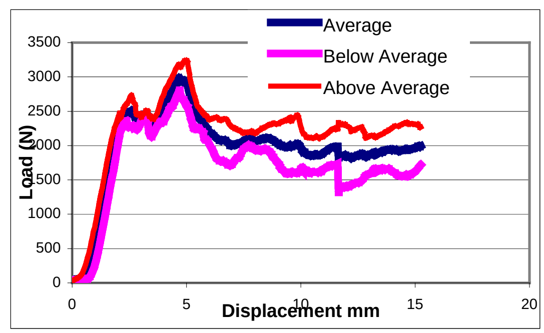

Figure 3 Load deflection behavior of a vertebral bone with 84% Porosity

SUMMARY

Fused deposition method (FDM) successfully fabricated the trabecular core and lumbar vertebral bone models. On an average, it took 1 hour to fabricate one vertebral bone sample These models produced compression load deflection behavior similar to that of the vertebral cadaver bones. The entire process of fabrication is relatively fast and inexpensive. This investigation suggests that FDM can be used to explore functional behavior of bony structures.

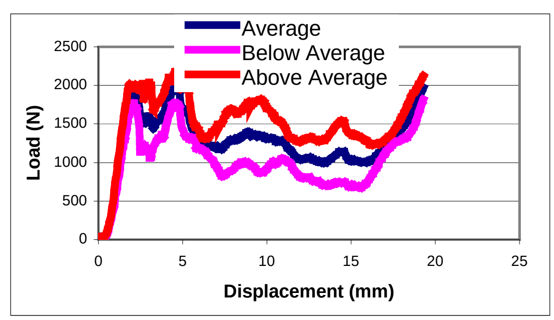

Figure 4 Load deflection behavior of a vertebral bone with 92% Porosity

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