

VIBRATIONAL ANALYSIS OF NORMAL AND OSTEOPENIC TRABECULAR BONE USING RAPID PROTOTYPED DUPLICATES

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INTRODUCTION

Osteoporosis is a systemic skeletal disease which increases bone fragility and susceptibility to fracture. Osteoporosis afflicts about 200 million people around the world [1] and osteoporotic fractures are estimated to be several millions annually in the US alone and cost tens of billions of dollars [1]. Characterization of bone quality in osteoporotic patients is very important with respect to monitoring treatment efficacy, however, currently quite limited. While some technical hurdles in developing a diagnostic tool using low frequency vibration have been overcome, many questions still remain including data interpretation and analysis. In particular, changes in the frequency response signal of bone have not been investigated at the various bone organizational levels. Our principal hypothesis is that the vibrational modes of bone tissue changes significantly with the deterioration of bone micro-architecture and that these modes can be captured by sensors to infer a structural compromise.

METHODS

Bone Models: Rapid prototyped duplicates of trabecular bone samples were fabricated based on digital scans of a lumbar vertebra excised from a female cadaver and obtained on a μ CT80 (Scanco Medical) with an isotropic resolution of 30 μ m. Through image manipulation, triangulated surfaces of a randomly selected bone cube taken from the lateral aspect of the vertebra were generated using the thresholded μ CT scans. This bone cube measured a bone mineral density (BMD) of 127 mg/cm^3 , with is within the normal range [2]. An available custom algorithm was used to reduce the overall bone mass of the normal bone cube to an osteopenic stage (BMD of 86 mg/cm^3). After scaling both models, digital files were exported to a rapid prototyping system, which fabricated a scaled up duplicate of both bone cubes with 20 cm edge length (Figure 1).

Vibrational Analysis [3, 4]: Dynamical responses were carried out by attaching the bone cubes to an active electro-dynamic shaker while simultaneously recording acceleration and dynamic force. Frequency Response Function (FRF) measurements were made using random broad band excitation signal. A sample rate of 2000 S/s with a Hanning time domain window allowed for a frequency resolution of 0.1 [Hz]. The experiments on the cubes were repeated three times in alternative order to ensure accuracy of the results. The power spectrums of the force and acceleration signals were computed. Acceleration signals were processed to derive velocity and displacement signals. Dynamic stiffness, half-peak bandwidth, and damping ratio (ζ) for both bone cubes were calculated using FRF measurements, and other techniques.



Figure 1: Scaled version of a normal (right) and osteopenic (left) bone cubes were made using rapid prototyping system.

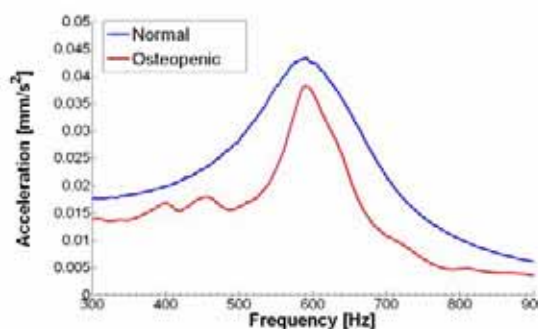


Figure 2: Power spectrums of acceleration signals from normal and osteopenic bone models (peak at 595 [Hz]).

RESULTS AND DISCUSSION

The normal bone model showed a light modal coupling in power spectrum, whereas the osteopenic bone model showed a heavy modal coupling with both models exhibiting a strong peak at 595 [Hz] (Figure 2). The half-peak bandwidths for the normal and the osteopenic bone were determined to be 265 ($\zeta = 0.10$) and 130 ($\zeta = 0.08$) [Hz], respectively. The dynamic stiffness of the osteopenic bone model was about one third of the normal bone model.

CONCLUSIONS

The results of the experimental modal analysis of the bone cube models representing the normal and osteopenic stages of trabecular bone have been discussed here. Although at a preliminary stage, the results have showed a clear difference between these two architectures. Current and further studies are underway to ensure the feasibility and reliability of a structural dynamics approach to detect early stages of bone loss.

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