METHOD FOR VERIFYING MECHANICAL PROPERTIES OF PROXIMAL TIBIA TRABECULAR BONE DERIVED FROM CT DATA

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INTRODUCTION

To develop more representative finite element models of human bone for use in finite element analysis (FEA), computer tomography (CT) data is used as a basis of mechanical properties and bone geometry. Individual element properties are mapped from the CT data through a series of processing steps that impact the finite element model material properties. A high level evaluation of the mapped properties relative to published physical test data can provide increased confidence in the process. This study provides a method for verifying that a CT scan derived proximal tibia finite element model will have mapped mechanical properties of trabecular bone supported by published data

METHODS

A lower limb CT scan from a patient aged 63, weighing 74 kg, and measuring 175 cm tall was taken in 1mm slices. Published data used as a basis for comparison was taken from mechanical testing done by Goldstein et al [1] on five cadaveric specimens from ages 50-70 years, described as average height and weight.

The patient's CT scan was imported into Simpleware's [2] Scan IP software. The tibia was segregated by thresholding. This technique selects pixels in the CT scan's slices above a certain Hounsfield Unit (HU) value. A HU is an X-ray attenuation unit used to interpret CT scan data, where a value of 0 is water and -1000 is air [3]. In this case a HU of 600 was chosen to represent the lower value for cortical bone to bound the trabecular volume [4]. Based on previous experience, a portion of trabecular bone may have the same apparent density as soft tissue surrounding the tibia, thus it is not feasible to threshold for HU less than cortical. The trabecular bone is selected after the cortical boundary has been defined by filling in the inner cavity of the cortical bone. The combined selection constitutes the complete tibia geometry.

The model was meshed with higher order tetrahedral elements using a second Simpleware module; Scan FE. The element size was based on the CT scan's native slice resolution of 1mm x 1mm with a thickness of 1mm. Mechanical properties were calculated based on established correlations between bone density and elasticity [4]. The Scan FE software calculated these values using the following equations from Rho et al [1]: $\rho = 114 + 0.916 * HU$ *and* $E = 0.06 * \rho^{1.55}$, where ρ is the density and E is elastic modulus. Each element in the finite element model was assigned a calculated elastic modulus based on a HU value that corresponded to the element's location in the CT scan. A Poisson's ratio of 0.3 was assigned globally.

The FE model was imported into ANSYS 11.0 [5]. A cutting plane was created in accordance with reference 1 protocol for the initial tibial plane resection.

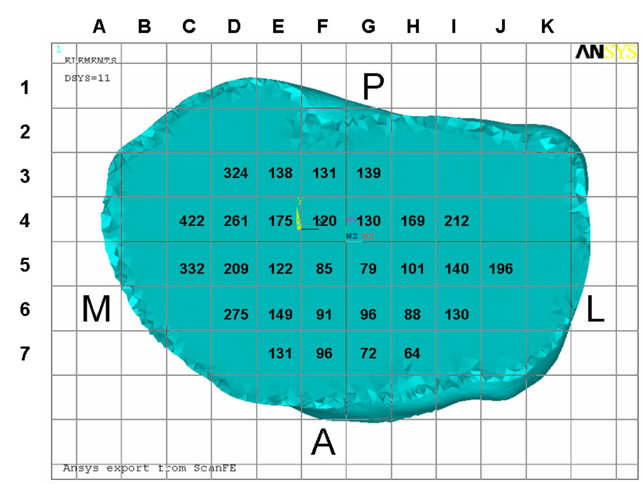

Figure 1: Resection with averaged elastic moduli values

A second cutting plane was developed 10mm distal to the initial tibial plateau resection resulting in a representative 10mm thick proximal tibia section. A 7mm square grid was superimposed on the resected surface to allow for sub-segregation of the mapped data. 7mm diameter cylinders were cut out of each grid square in each section. The moduli of elements inside each cylinder were averaged. Figure 1 shows the resection surface of the FE bone model with average elastic modulus values. The resulting average values were then compared to values obtained from Goldstein et al shown in Figure 2.

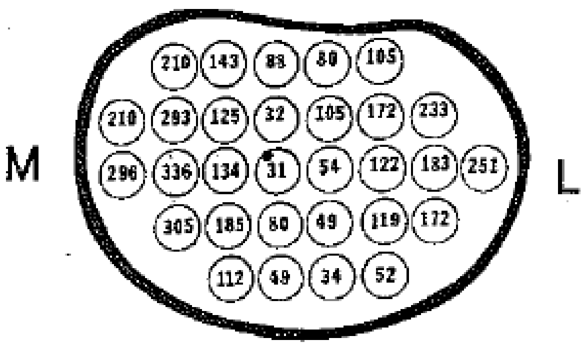

Figure 2: Elastic Moduli map from Goldstein et al.

RESULTS AND DISCUSSION

Figure 3 (A & B) summarizes elastic modulus data from the FE model compared to published data from ref 1 for the first 10mm of resected proximal tibia per the grid if Figure 1. 19 of the 30 regions moduli values fell within one standard deviation (sd) of ref 1 data. 26 of 30 regions fell within 2 sd and 29 of 30 regions fell within 3 sd.

Ensuring FE model material property accuracy is critical to the model development. Due to the number of steps and tools that may be used in the process of developing a FE model from CT data, a high level property verification tool can be used to ensure the model is representative. Although the CT scan patient data was outside the published physical test specimen group, 70% of the FE model's elastic modulus values fell within 1 sd, 86% fell within 2sd and 97% fell within 3sd with similar location trending. Comparative result differences are expected due in part to gender, age, ethnicity and weight and should be considered when comparing results.

This method will be further developed in future work comparing matched data from mechanical testing of cadaver specimens with matched CT scan data, eliminating potential variability between patients

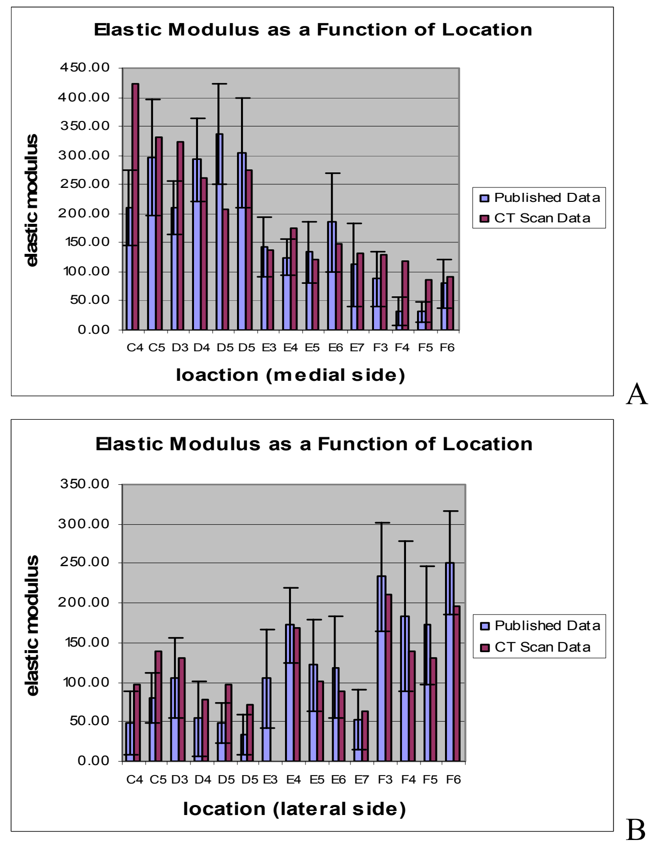

Figure 3: Elastic Modulus as a Function of Location from Figure 1, A represents the medial side and B the lateral side.

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