A Framework for Estimating Bone Strength Along the Distal Radius and the Effect of Eccentric Axial Load Position

INTRODUCTION:
Tissue level finite element (FE) models derived from microCT scans have demonstrated the potential for estimating macroscopic bone strength of the distal radius with a reasonable degree of fidelity [1,2]. However, the computational requirements, documented benefit over traditional measures, and ability to validate those models with experimental data have limited the widespread adoption of those models in the clinical environment. Due to those limitations, microFE models of the distal radius are often only evaluated in constrained compression, resulting in a single representitive value of bone strength [3,4,5]. However, Troy and Grabiner [6] showed that the loading condition (i.e. combination of axial compression and bending) significantly affects the predicted failure force, suggesting that a single bone strength value is not appropriate for all conditions. The purpose of this study is to present a framework for analyzing microCT axial images of the distal radius using an engineering based approach for estimating fracture strength from axial and bending forces that is not constrained by extensive computational requirements (i.e. experience with microFE software, analysis times exceeding several hours, substantial computer RAM, etc.). The effect of the position of the axial slice and the position of the eccentric axial force are also presented.

METHODS:
Five left radii were excised from fresh frozen cadavers and analyzed as described below. The results for a single specimen, which were typical of all the analyzed specimens, are presented. The results of the excised left radius presented here were from a forearm harvested from a 74 year-old male donor (178 cm, 69 kg). The intact radius was scanned with a Scanco vivaCT 40 microCT scanner using the following settings: 55kVp, 145 µA, 1000 ms integration time, 19 µm voxel size; a 1200 mg/HA/cm³ beam hardening correction algorithm was also applied. Ten evenly spaced slices along the axial direction (Figure 1, lower right) were used for the analysis. Bone tissue was segmented using a constant even spaced slices along the axial direction (Figure 1, lower right). Several aspects of the framework must be evaluated in greater detail before prior to justification that the derived metrics would provide additional clinically relevant information over traditional measures. First, the definition of macroscopic failure (i.e. fracture) as implemented here is dependent on the assumed yield strain of bone tissue and the total number of tissue elements that must ‘fail’ prior to macroscopic fracture, first conducted a sensitivity study using a similar failure criterion applied to a 3D FE model and found that predictions best fit the experimental data when 2% of the bone voxels exceeded the yield strain, however that approach may not be the most robust when only using 2D axial slices. Second, to predict clinically relevant fracture risk, appropriate boundary conditions must be derived and validated ex-vivo, a procedure that has yet to be performed under any modeling paradigm. Third, the 3D structure is analyzed here as a simplified 2D slice (or group of slices) and the effect of that simplification on the fidelity of predicted fracture force previously observed for 3D FE models must be evaluated. The results from the color figure highlight that for axial loads with high eccentricity, either dorsal or volar, the strength increases only moderately when proceeding from distal to proximal slices. For axial loads applied more centrally, the distal slices are substantially weaker than the proximal slices. Future tools, particularly those proposed to enhance the clinical assessment of bone strength, must identify appropriate input loading conditions so that an accurate relationship between relevant failure modes can be derived.

REFERENCES:

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