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MULTI-MODALITY CT IMAGING OF HUMAN BONE FOR IMPROVED VALIDATION OF SUBJECT-SPECIFIC FINITE ELEMENT ANALYSIS

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INTRODUCTION

Finite element analysis (FE) is a promising alternative to dual-energy x-ray absorptiometry for improved prediction of fracture risk as FE can incorporate bone density, geometry, and microarchitecture [1]. However, the accuracy of FE models is heavily influenced by the spatial resolution of the CT scan [2]. In this study we quantify the architectural differences in trabecular bone between different modalities, specifically high-resolution peripheral quantitative computed tomography (HR-pQCT) and micro-computed tomography (µCT), and measure their effect on the resulting FE models.

METHODS

Two cadaveric, human distal tibiae were imaged using HR-pQCT (XtremeCT, Scanco Medical, Switzerland), with a voxel size of 82µm. After imaging, four cubes, 10mm edge length, were cut and scanned using µCT (µCT-35, Scanco Medical, Switzerland.), with a voxel size of 20µm. During a sensitivity analysis, the µCT image data was segmented using a threshold based technique and resampled to voxel sizes of 40µm, 60µm, and 80µm to assess the effect of voxel size on the FE results. The FE results were statistically compared with a one-way repeated measures ANOVA and a Tukey's post-hoc test.

Based on the known location of each cube recorded during the cutting process, the µCT data was manually aligned to the larger HR-pQCT image, where mutual information registration was applied for accurate alignment. Virtual cubes were extracted from the registered HR-pQCT data. All cube image data was rescaled to preserve the bone volume/total volume ratio. Subsequently, all image data was converted to hexahedron elements for FE analysis and subjected to 1% uniaxial compression (FAIM v6.0, Numerics88) in the x-, y-, and z-directions. The resulting FE data was compared with a two-way ANOVA, with Bonferroni multiple comparisons test.

RESULTS

The sensitivity analysis found no statistically significant differences in reaction force between any cubes with different resolutions when compressed in the z-direction. The mean percent error, when compared to the 20µm cube, for the 40µm, 60µm, and 80µm cubes was 0.06%, 0.45%, and 0.76%, respectively. In the y-direction, there were significant differences between the 20µm and the 80µm ($p < 0.01$; 62.51% error). When loaded in the x-direction, there were significant differences between the 20µm FE cube and the 60µm and 80µm FE cubes ($p<0.05$; respective mean percent errors of 121.27% and 182.83%). With increasing voxel size, the reaction force was overestimated. As shown in figure 1, the registration between µCT and HR-pQCT was successful. However, there were statistically significant differences found between the µCT versus HR-pQCT FE data in the y- and x-direction ($p<0.01$; 23.95% and 21.04% error, respectively) but none were found for the z-direction ($p>0.05$, 0.14% error.)

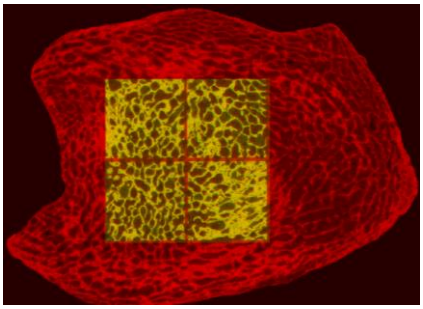

Figure 1. Registered distal tibia (HR-pQCT - red) to the µCT acquired cubes (yellow). The registered image appears green in overlap.

DISCUSSION AND CONCLUSIONS

It was shown there is little difference in the FE results loaded in the z-direction upon rescaling µCT data (mean percent errors less than 0.8%). However, there are large changes in the non-axial (i.e. x and y) directions. It is recommended that µCT data be rescaled up to 40µm. In addition, it was shown that µCT data could be successfully registered to HR-pQCT (see figure 1). For a given resolution, µCT data is only comparable to HR-pQCT data in the z-direction. In conclusion, HR-pQCT may not be an ideal substitute for µCT micro-architectural data. This study improves our understanding on the use of HR-pQCT imaging for quantification of bone micro-architecture.

REFERENCES

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