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Effect of Voxel Size on Finite-Element Analysis of Micro-CT Derived Bone Sample

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Abstract

Introduction: Bone strength is dependent on the structural parameters of the trabecular micro-architecture[1]. A method to estimate bone strength is finite element (FE) analysis of the bone micro-architecture[2]. Quantification of structural parameters[3] and FE analysis results are dependent on the image resolution[2]. This study used micro-computed tomography (micro-CT) to investigate how voxel size affects the accuracy of trabecular bone measurements, particularly regarding how it relates to FE modeling prediction of bone strength.

Methods: Cadaveric bovine cubic bones were imaged at an isotropic voxel size of 20μm using a micro-CT scanner (Micro-CT35). Images were segmented using a threshold based technique and re-scaled to voxel sizes 2-4 times larger (40μm-80μm) than the original images. Three-dimensional analyses of trabecular bone properties were quantified within the images of the bone cubes. Image voxels were converted to hexahedral elements for FE analysis. Uniaxial 1% compression test was performed on all data (FAIM 5.4). Nodes on the bottom surface were fixed while the top surface was subjected to compression. No constraints were applied to the x and y directions.

Results: Trabecular number (TbN) measurements increased linearly with increasing resolution. There was a 22.11% difference between trabecular number values at 20μm versus 80μm. All other structural parameters were not statistically significant between different image resolutions ($p > 0.05$). For FE analysis, there was a 3.05% percent difference for mean von-Mises Stress at 20μm versus 80μm. Total reaction force between 20μm and 80μm differed by 0.484%. Maximum von-Mises stress was statistically significantly different between 20μm and 80μm.

Conclusion: All structural parameters except TbN measured at 20μm are comparable to 80μm. Similarly, bone strength estimates through FE analysis at 20μm are comparable to 80μm. It is unlikely that TbN influenced the bone strength estimates. These results will allow for non-invasive estimate of bone strength with advanced clinical CT scanners.

References

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