Decrease in elastic modulus of cancellous bone due to misalignment depends on bone volume fraction and degree of anisotropy

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Introduction: Since cancellous bone is found in regions of the skeleton where age- and disease-related fractures most commonly occur, accurately measuring its mechanical properties is important. Ensuring proper orientation of test samples in such an anisotropic material is difficult. As a result, one experimental study found that the apparent modulus (E) may be underestimated by up to 40% due to misalignment [1]. The magnitude of this error, however, is expected to be highly dependent on the cancellous architecture. The current study uses finite element method (FEM) modeling to establish the dependence of misalignment error on architectural parameters.

Methods: Specimens were cut from five bovine skeletal sites, µCT scanned at 15 µm, and analyzed to determine the degree of anisotropy (DA) and bone volume fraction (BV/TV). After an initial estimate, the primary mechanical axis (PMA) for each specimen (i.e., the orientation with the highest E) was identified to within 1° via an iterative search based on FEM model results. Cylindrical samples (8mm dia. x 10mm) were then cropped from the central region of each image, with their centrelines misoriented at 5° or 20° relative to the PMA and converted to FEM meshes. All models were compressed to 0.1% strain to calculate E. In addition to these *conventional models*, specimens were subjected to Boolean erosion/dilation steps to create new models with constant BV/TV values. FEM meshes of these *eroded/dilated models* were created following the steps described above. Misalignment error (ΔE) was calculated relative to E along the PMA.

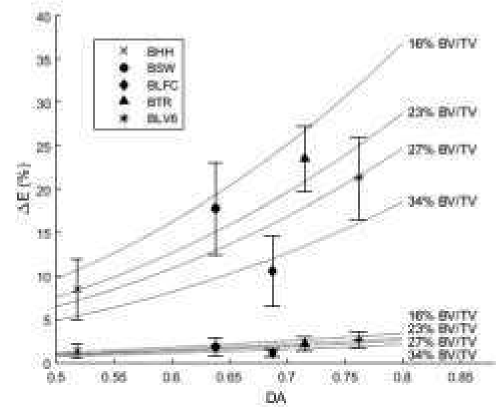

Figure 1. Conventional model results. Upper 4 fits represent 20° misaligned, while the bottom 4 represent 5° misaligned. Error bars represent SD.

Results: A Kruskal-Wallis test indicated that the models had significantly different response to off-axis loading ($p<0.05$). Least-squares fits were applied to both the conventional (Fig. 1) and eroded/dilated data and the decrease in modulus was found to be dependent on DA and BV/TV by an equation of the form: $\Delta E = a(BV/TV)^b(DA)^c$.

Discussion and Conclusions: Bovine cancellous bone from different skeletal sites had significantly different responses to off-axis loading. At 5° misalignment, ΔE was relatively low (<5%) but increased with misalignment. Our findings indicate that high DA, low BV/TV regions are most susceptible to misalignment error. Therefore, test specimen alignment should be of greatest concern to researchers studying osteoporotic effects in regions such as the vertebrae.

References:

[1] Öhman C, et al (2007) Journal of Biomechanics. 40(11):2426-33