PREDICTING BONE STRENGTH LOSS USING VOXEL BASED MORPHOMETRY AND FINITE ELEMENT MODELING

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Introduction

Fragility fractures at the hip can lead to significant adverse health outcomes and the lifetime risk of hip fracture is estimated to be 17% for women and 6% for men [1]. Finite element modeling (FEM) based on quantitative computed tomography (qCT) can be used to estimate bone strength, which can be used as a surrogate for estimated fracture risk.

Voxel Based Morphometry (VBM) is a technique used to compare similar but different images [2]. Using VBM, baseline and follow-up qCT scans can be registered to one another to create average bones across femurs of different shapes.

In this study, we used VBM to estimate average bone loss over an 18-month period, and then used the estimated average bone loss to predict the bone strength changes using FEM on a separate validation subset.

Methods

qCT scans from 107 subjects were selected from the UPLIFT weight loss clinical study (NCT03074643). Both baseline and 18-month follow-up qCT scans were available for each selected subject.

The femurs were segmented and registered (ANTsPy 0.3.1) to a template femur. The registered baseline scan was subtracted from the registered follow-up scan to create a map of the bone loss for each subject. For 99 of the 107 subjects, these differences were averaged at the voxel level to create an average amount of voxel-based density change.

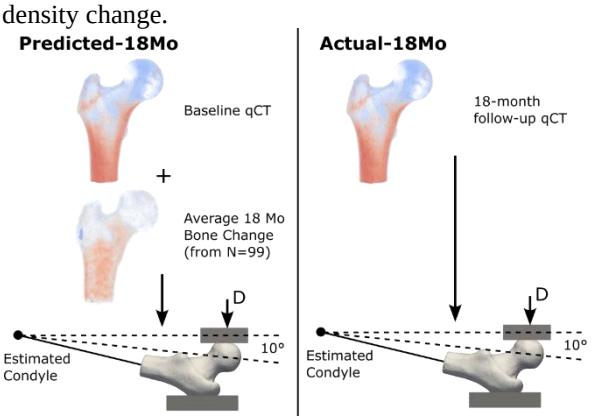

Figure 1: Construction of the Predicted-18Mo and Actual-18Mo simulations for the 8 validation subjects. Displacement (D) is applied at the top boundary condition, and forces are measured across the neck.

The remaining 8 subjects were used as validation, and the average bone loss was applied to the baseline scans to create "Predicted-18Mo" models. Simultaneously, the 18-month follow-up qCTs were used to create an "Actual-18Mo" model. In this way, the Predicted-18Mo models use only baseline information and the average 18-month bone changes, while the Actual-18Mo models represent the actual bone at 18-month follow-up.

FEM was used to estimate the femur strength of the Predicted-18Mo and Actual-18Mo bones [3]. Briefly, femur models have density-based strain-rate dependent material properties with damage modeling derived from the qCT greyscale values. The neck was aligned with the loading axis, the adduction angle was 10 degrees, and a displacement boundary condition was applied to the femoral head. The maximum force through the femoral neck was considered the femoral strength.

Results

Predicted-18Mo simulations predicted a much smaller bone strength decrease (mean: -0.02kN; 95% CI: -0.13, 0.09kN) than the Actual-18Mo simulations (-0.24kN; -1.35, 0.87kN). Across all simulations, differences between the Predicted-18Mo vs. Actual-18Mo femur strengths averaged 0.22kN and ranged from -0.50kN to 1.36kN.

Discussion

In this study, we attempted to "age" baseline qCT scans to create models that simulated the bone loss over an 18-month period. Our predicted strengths substantially underestimated the amount of bone strength loss.

As we used an average bone change to "age" the qCT scans, differences between the Predicted-18Mo and Actual-18Mo were expected for individual subjects. However, we did not expect the mean strength loss to differ so greatly. Our "aging" process does not change the geometry; however, the geometric changes could play an important role in strength changes.

Future work should focus on investigating average and subject-specific longitudinal bone geometry changes in addition to bone density changes.

References

1. Cummings et al., *The Lancet* 2002
2. Ashburner et al, *Neuroimage* 2000
3. Fleps et al, *Bone* 2022

Acknowledgements

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