Indentation Properties of the Human Distal Tibia

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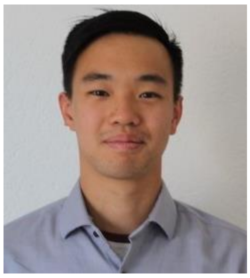

Introduction

To assess osteoporosis patient fracture risks, 3D reconstructions of high-resolution peripheral quantitative CT (HR-pQCT) allow non-linear homogenized finite element models (hFE) to predict in vivo bone strength and stiffness at peripheral sites such as radius and tibia [1]. To improve the strength prediction of the hFE analysis, accurate measurements of bone material properties are required and mainly defined experimentally or by simulation with finite element analysis (FEA). An experimental indentation procedure quantifies material properties by measuring the force and displacement of a hard tip with known properties pressed into the material to characterize [2]. The aim of this study was to assess the material properties of cortical and trabecular bone of the human distal tibia using the nanoindentation technique.

Materials and Methods

Ten tibia sample slices of 5mm originating from a previous study were prepared for indentation. Sample preparation ensures a good surface quality and high parallelity between the top and bottom surfaces for subsequent indentation (See Fig.1).

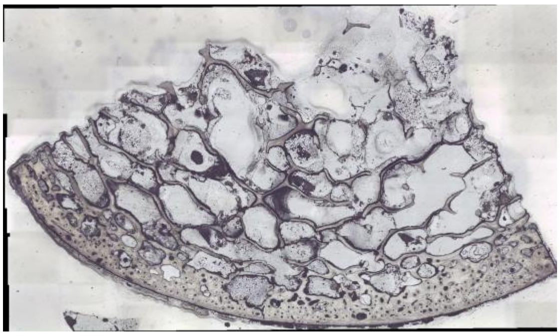

Fig. 1 Image of a sample surface after polishing reconstructed by stitching

The samples were tested in dry conditions by applying a predefined trapezoidal loading protocol of a fixed depth of 1μm (Ultra Nano hardness Tester II UNHT, Anton Paar, Switzerland). In total, 1200 indents for all samples were applied in the axial direction, corresponding to 120 indentations distributed equally over 10 regions on interstitial lamella, osteons and trabecula structures. A two-level linear mixed-effects (LME) model was implemented with the resulting plane strain moduli to estimate their value for the 3 structures and the variances due to sample donors and indentation regions within samples. A correction factor was applied to the results obtained in dry to simulate compared wet conditions.

Results

The plane stress moduli for each structure resulting from the analysis are ranged with their 95% confidence interval (CI) from 22.4 GPa with 95% CI [21.6 - 23.2] GPa in interstitial lamellae, 19.0 GPa with 95% CI [18.2 - 19.8] GPa in osteons and 12.6 GPa with 95% CI [11.8 - 13.4] in trabeculae (See Fig. 2). Compared to literature studies, the experimental measures for each structure were lower in both dry and physiological conditions. Region within samples have shown to have a significant effect ($p<0.05$).

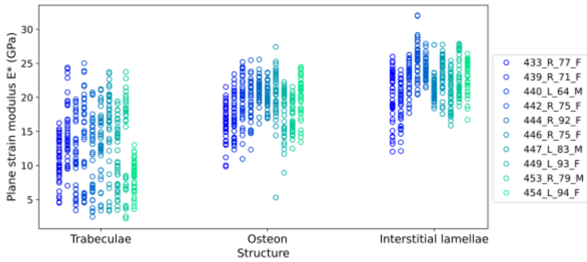

Fig. 2 Scatter plot of experimental plane strain moduli between trabeculae, osteon and intertial lamellae structures

Discussion

Clear distinctions between each structure measure are assessed by nanoindentation. Indentations were applied in several orientations caused by minor parallelity differences. Additional donor-specific parameters of the sample could be considered, such as localized tissue mineral density (TMD) or collagen orientation. within the bone that influences the material properties.

References

[1] D. Schenk et al., 'Unified validation of a refined second-generation HR-pQCT based homogenized finite element method to predict the strength of the distal segments in radius and tibia,' Journal of the Mechanical Behavior of Biomedical Materials, vol. 131, p. 105235, Jul. 2022

[2] P. K. Zysset, 'Indentation of bone tissue: a short review,' Osteoporos Int, vol. 20, no. 6, pp. 1049–1055, Jun. 2009

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