Preliminary Investigation into the Co-variation of Cortical Geometric Properties and vBMD along the Length of the Tibia.

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I. INTRODUCTION

Functional adaptation of bone to its mechanical environment involves regulation of both geometry and material properties contributing to its fracture resistance. Co-variation in these properties has been investigated between individuals and across the skeleton [1-2] but has yet to be quantified along the cortical diaphysis of one bone. Changes in the structural properties as a function of total length may occur and affect potential whole bone response to injurious mechanical loading. Heterogeneity in localized parameters contributing to whole bone response has implications for understanding fracture patterns. The purpose of this study was to quantify the intra-element co-variation in cross-sectional geometric properties with a proxy for material properties (volumetric bone mineral density or vBMD) in the tibia.

II. METHODS

This sample includes 39 post-mortem human subject (PMHS) males ranging in age from 25 to 87 years old (mean of 63.9 ± 12.5 years) donated through The Ohio State University Whole Body Donor program. A dual x-ray absorptiometry scan was performed on each PMHS after which lumbar (L2-L4) t-scores were used to classify these individuals similar to clinical standards of practice [3]. Un-embalmed left tibiae were then excised from each PMHS. Computed tomography (CT) scans were obtained using a clinical Philips Vereos digital PET/CT with iDose reconstruction software located at the Wright Center for Innovation in Biomedical Imaging (WCIBMI) located at The Ohio State University. Acquisition parameters were consistently maintained with a 1024x1024 matrix size resulting in a resolution of 0.335mm per scan. To evaluate vBMD, a QRM cortical phantom with standards of known densities of calcium hydroxyapatite (ranging from 0-800 mg/cm^3) was included in acquisition.

Whole tibiae CT scans were imported into OsiriX MD (v.8.0.1) software for segmentation. Total tibial length was measured between the tibial plateau and distal joint surface and used to segment the diaphysis into 38%, 50% and 66% of total length (Fig.1). Each resulting transaxial slice (0.671mm thickness) was exported for analysis in ImageJ (NIH) using a custom MomentMacro code to quantify cross-sectional properties including cortical area (Ct.Ar) and section modulus (Z) defined as area moment of inertia (I, mm^4) divided by distance to the outermost pixel of bone in the cross-section (mm). vBMD measurements for each volume of interest (VOI) included 10 slices (6.71mm) centered around 38%, 50% and 66% segment sites (Fig.1). The commercially available Skyscan CTAn (Bruker) software calculates vBMD by constructing calibration curves using gray scale values (Hounsfield units) produced by the phantoms of known densities in comparison to values within each cortical VOI. The average vBMD across all 10 slices is reported for each segment site.

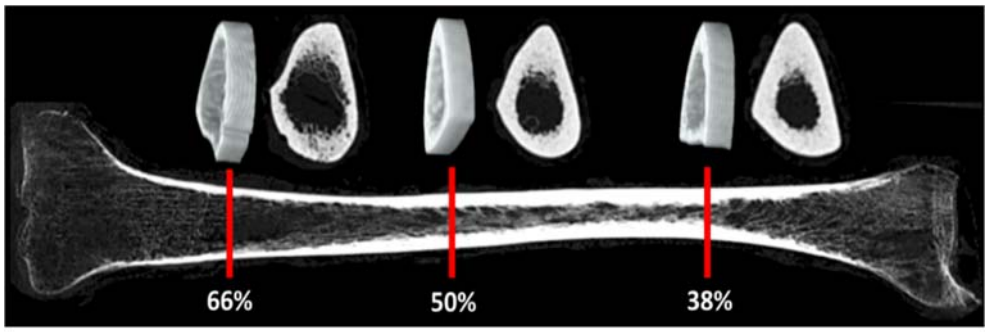

Fig. 1. Representative tibia CT scan. Center slices displayed with corresponding VOI.

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III. INITIAL FINDINGS

All PMHSs included in this study were classified as *non-osteoporotic* by lumbar t-scores > -2.49 [3]. Paired samples t-tests indicate significant differences ($p<0.001$) in Ct.Ar, Z and vBMD between all sites. Geometric properties significantly increase from distal to proximal; whereas, vBMD significantly decrease from distal to proximal (Fig. 2). Pearson correlations indicate no significant relationships between Ct.Ar or Z and vBMD at any segment site ($p>0.335$).

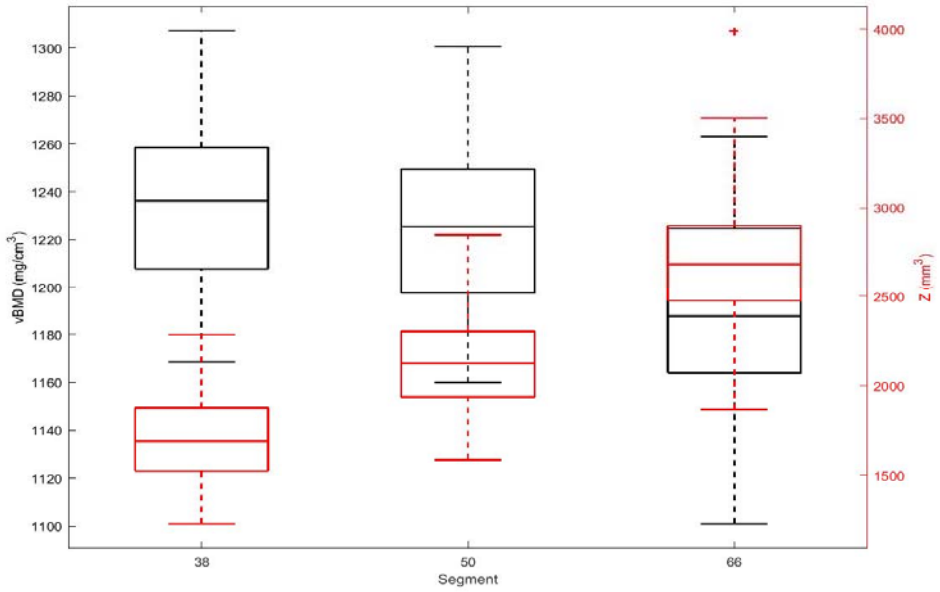

Fig. 2. Boxplot vBMD (left x-axis, black) and Z (right x-axis, red) per segment site demonstrating an increase in Z but a decrease in vBMD from distal (38%) to proximal (66%) in the tibial diaphysis.

IV. DISCUSSION

This novel quantification of intra-element co-variation in geometric and material properties demonstrates the functional adaptation of the weight bearing tibia wherein, smaller bone volume (Ct.Ar) and lower resistance to bending (Z) are compensated for by an increase in mineralization (vBMD) to a varying degree dependent on segment site or location. Previously, vBMD and Ct.Ar have been shown to co-vary across the skeleton with respect to robusticity, a predictor of whole bone strength, in which case slender phenotypes compensate for less bone volume with an increased level of mineralization [1-2][4]. These studies demonstrated systemic functional adaptation at the midshaft only of both weight and non-weight bearing bones [1-2]. The data presented here are the first to consider a more localized response to geometric changes that varies along the length of the cortex by which cellular machinery function to increase mineralization for smaller bone volume to maintain function. The lack of correlations between Ct.Ar or Z and vBMD at each segment site indicate confounding processes, likely at the microstructural level, which these methodologies are unable to capture. Future work includes dynamic mechanical testing of these tibiae to determine any tangible effects on variation in fracture risk across the cortex. Additionally, similar intra-element comparisons will be made to investigate the functional adaptation and compensation within non-weight bearing bones such as the radius and rib.

V. REFERENCES

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