Preliminary Intra-skeletal Variability in Male PMHS Pelvis vBMD

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I. INTRODUCTION

Pelvis injuries in motor vehicle crashes (MVC) persist in traditional seating configurations [1] and are likely to remain an issue for vehicles equipped with automated driving systems (ADS) and/or those with unconventional seating design. Previous experimental work encompassing a variety of combinations of loading scenarios and post-mortem human subject (PMHS) positioning have investigated pelvis kinematics, injuries, as well as lap-belt and vehicle seat interactions [2–4]. The variability in documented pelvis injury severity and anatomical location has prompted a call for investigations concerning the geometric, material, and structural differences in the pelvis between and within individuals [2]. Volumetric bone mineral density (vBMD), a frequently utilized metric for determining bone quality or interpreting results in injury biomechanics studies, has been shown to vary across the skeleton [5] but this has yet to be explored within the pelvis. Given experimental evidence of the contribution of BMD to pelvic injury tolerance [6], quantifying localized differences in the measure could contribute to an understanding of injury outcomes for a multitude of crash scenarios. Thus, the objective of this preliminary study was to quantify variation in vBMD across the pelvis of male PMHS.

II. METHODS

Retrospective analyses of whole-body Computed Tomography (CT) scans were performed for 89 male PMHS ranging in age from 24–87 years (mean: 64.1 ± 11.1) and representing a wide range of body sizes (BMI range 13.3-32.8; mean 24.0 ± 3.6). Each scan included an INTable^{TM} phantom with rods of known density (0, 75, 150 mg/cm^3) for vBMD calibration. Consistent CT acquisition parameters included a 512 x 512 matrix, 0.6mm slice thickness, 120 kVp, and a reference mA of 250. To ensure standardization across scans for analyzing multiple anatomical sites, each pelvis was reoriented and re-sliced using standard anatomical landmarks such that the axial plane was parallel to the pelvic floor and perpendicular to the most superior aspect of the iliac crests. The center slice of the reoriented pelvis (Fig. 1A) in which all anatomical sites could be visualized for further segmentation, was determined using the superior and inferior borders of the superior pubic ramus. Volumes of interest (VOIs) were manually created to represent bilateral regions of interest (ROI) including the superior pubic rami (SPR), anterior and posterior acetabulum (AntAC and PosAC, respectively), and the posterior ilium (Il) (Fig. 1). Anatomical sites were chosen based on injury patterns from previous whole-body experimental studies reported in [2]. vBMD was quantified using a standardized methodology [5] in OsiriX MD software (v.14.1.1). Statistical analyses were performed using Minitab (v.22.2.1) with *a priori* $\alpha=0.05$. Paired t-tests compared matched left and right VOIs. Repeated measures one-way ANOVAs quantified differences in vBMD per tissue type (Trabecular and Total).

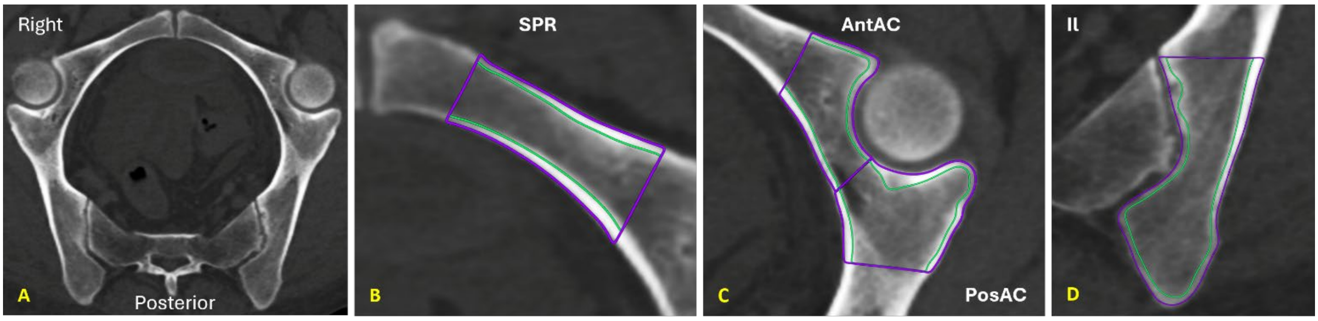

Fig. 1: Exemplar reoriented pelvis slice (A); anatomical sites for left SPR (B), Acetabulum (C), and Ilium (D) with segmentation of Tb (green) and Total (purple) non-thresholded VOIs

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III. RESULTS

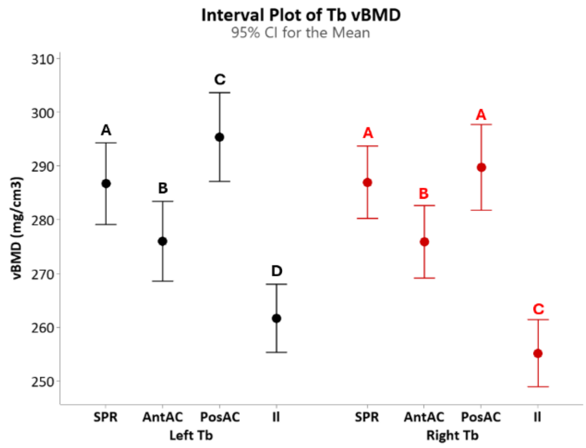
vBMD data were normally distributed (Kolmogorov-Smirnov p>0.05). Table I demonstrates asymmetry in vBMD between some of the left and right VOIs. The left PosAC Tb vBMD was significantly higher than the right (p=0.007). However, there were no side differences for the PosAC Total vBMD indicating greater homogeneity when including cortical bone that may overshadow trabecular differences. In both tissue types, the left Il vBMD was significantly greater than the right which may be a result of different load distribution through the sacroiliac joints.

TABLE I
LEFT AND RIGHT vBMD COMPARISONS

Tissue Type	L SPR	R SPR	p	L AntAC	R AntAC	p	L PosAC	R PosAC	p	L Il	R Il	p
Tb	286.7±36	286.9±31	0.9	276.0±35	275.9±32	0.9	295.3±39	289.7±37	**0.007**	261.7±30	255.2±29	**<0.01**
Total	481.3±69	478.0±71	0.4	361.8±51	366.2±48	0.1	428.3±61	424.9±60	0.2	354.2±41	346.8±41	**0.005**

******all data in mg/cm^3*

Comparisons across anatomical sites were performed for each side (Fig. 2). All sites were significantly different in left Tb bone (p<0.01) whereas, right SPR and PosAC were not significantly different (p>0.05). For Tb bone, the PosAc site had the highest vBMD values followed by SPR, AntAC, and Il. Alternatively, the SPR VOIs had the highest values in Total vBMD. For both sides, Total vBMD at the AntAC and Il VOIs were not significantly different (p>0.05) while the PosAC and SPR had progressively higher vBMD values (p<0.05; Fig. 2).



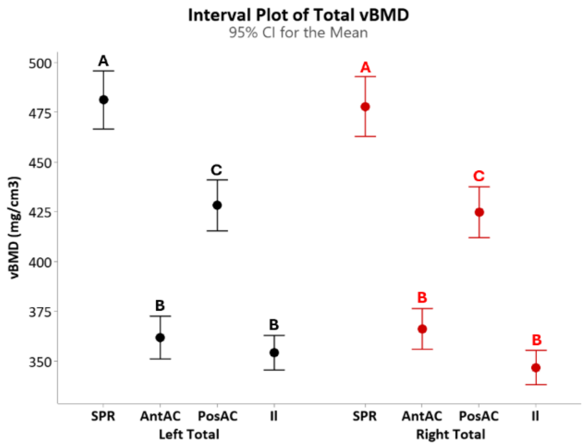


Fig. 2: Tb (left) and Total (right) vBMD for left (black) and right (red) sides (different letters designate statistical differences per side)

IV. DISCUSSION

This study found vBMD differences across anatomical sites in the male pelvis suggesting a localized approach to evaluating this metric is necessary. Given pelvis trauma is the most frequent AIS2+ lower extremity injury in side and oblique MVCs [6], innovative models to capture pelvis geometry have found demographic and anthropometric variables can only explain 29% of its variation [7] further supporting the consideration of local complexity in structure and material. Variations in Tb and Total vBMD between sides and across sites are likely due to biomechanical differences from lower limb dominance and could combine with structural and geometric variation to influence load paths and distribution which may explain differential injury patterns. In high-speed rear facing frontal impact scenarios, [2] demonstrated variable severity and locations of pelvic fractures ranging from no injuries to multiple bilateral fractures of the posterior ilium and pubic rami attributed to an "open book" deformation. Future work will characterize the local pelvic vBMD for male PMHS utilized in [2] to investigate the contribution of bone density to injury risk in dynamic loading scenarios. vBMD from additional anatomical sites (e.g., anterior ilium) could be analyzed to address injury patterns associated with lap-belt loading.

V. REFERENCES

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