Bone Area vs Cortical Area: Considering Intracortical Porosity When Predicting Rib Structural Properties

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I. INTRODUCTION

The thorax plays a significant role in the protection of vital organs, but is an area particularly susceptible to injury in the context of a motor vehicle crash. Increasing age results in higher risk and severity of thoracic injury, suggesting that the structural and material properties of the ribs, also thought to vary with age, may play a part in compromised thoracic injury tolerance [1]. Human ribs are highly susceptible to bone loss with age, particularly in the cortex. Endosteally, cortical bone trabecularizes, resulting in expansion of the medullary cavity at a rate typically exceeding periosteal apposition, leading to the largest source of net bone loss by reducing cortical area [2]. Intracortical bone loss occurs between the periosteal and endosteal borders; however, it is less severe than endocortical loss, and is characterized by increases in Haversian canal size and the coalescence of multiple remodeling events [3]. This results in reduced bone area that is often not reflected in cortical area measures, but may influence the structural response of the rib. Cortical area has potential as a variable for predicting the rib's response to loading, with diminished cortical area expected to decrease structural properties. While cortical area may account for the diminution in endosteal cortex with age, the role of intracortical porosity has yet to be considered. This study examines the influence of intracortical porosity and bone area in regard to the structural response to loading.

II. METHODS

The sample consists of 108 human mid-thoracic ribs (levels 4–7) from both sexes (female *n* = 20, male *n* = 80) with ages between 15–99 years (mean = 49, sd = 24). Whole ribs were acquired from donors to The Ohio State University Body Donor Program or Lifeline of Ohio, USA. The test set-up consists of a custom pendulum fixture designed to simulate a dynamic frontal impact, assuming a two-dimensional bending scenario. Forces and moments were recorded using a six-axis load cell (CRABI neck load cell, IF-954, Humanetics, Plymouth, MI) and displacement was measured using a linear string potentiometer (Rayelco P-20!, AMETEK, Inc., Berwyn, PA). Structural properties calculated included in this study are peak force, linear structural stiffness, and total energy to fracture (for further details of the experiment and definition of structural properties see [4]).

Two centimeter blocks from the midshaft (30–70% of the curve length) were excised, macerated, and embedded in plastic prior to thick sectioning. Undecalcified sections were cut at ~70 µm on a diamond wire saw, mounted on glass slides, and coverslipped following standard histological protocol. Slides of the complete cross-sections were imaged at 40X magnification under bright field illumination and all histomorphometric data were collected manually via a digitizing pen and tablet and ImageJ software [5].

Cortical area (Ct.Ar) was calculated by subtracting the endosteal area (i.e., medullary cavity area) from the periosteal area (i.e., total area). Porosity area (Po.Ar) refers to the total area of open spaces within the cortex (i.e., Haversian and Volkmann's canals, and resorptive bays; but excluding canaliculi and osteocytic lacunae). Percent cortical porosity (%Ct.Po.Ar) is a standardized measure used to assess differences in porosity while accounting for allometry; it is calculated as (Po.Ar/Ct.Ar)*100. Bone area (B.Ar) is the actual amount of cortical bone present after accounting for porosity, calculated by subtracting Po.Ar from Ct.Ar.

Preliminary statistics assessed the relationship between histomorphometric variables and age, as Ct.Ar and %Po.Ar have been shown to vary with age [6]. A paired samples *t*-test assessed whether histomorphometrically derived Ct.Ar and B.Ar were significantly different and linear regressions were applied to examine how accurately Ct.Ar and B.Ar each predict peak force, stiffness, and total energy.

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III. INITIAL FINDINGS

Preliminary findings demonstrate a trend of decreasing Ct.Ar ($R^2 = 0.17$), as well as decreasing B.Ar ($R^2 = 0.22$) resulting from an increase in %Ct.Po.Ar ($R^2 = 0.31$) with increasing age. Sex differences were not assessed due to sample size discrepancies. A paired sample *t*-test shows significant differences in the amount of Ct.Ar and B.Ar ($p < 0.001$). Linear regressions suggest that B.Ar measurements are better at predicting peak force, stiffness, and total energy than Ct.Ar measurements. However, the improvement is small (Fig. 1).

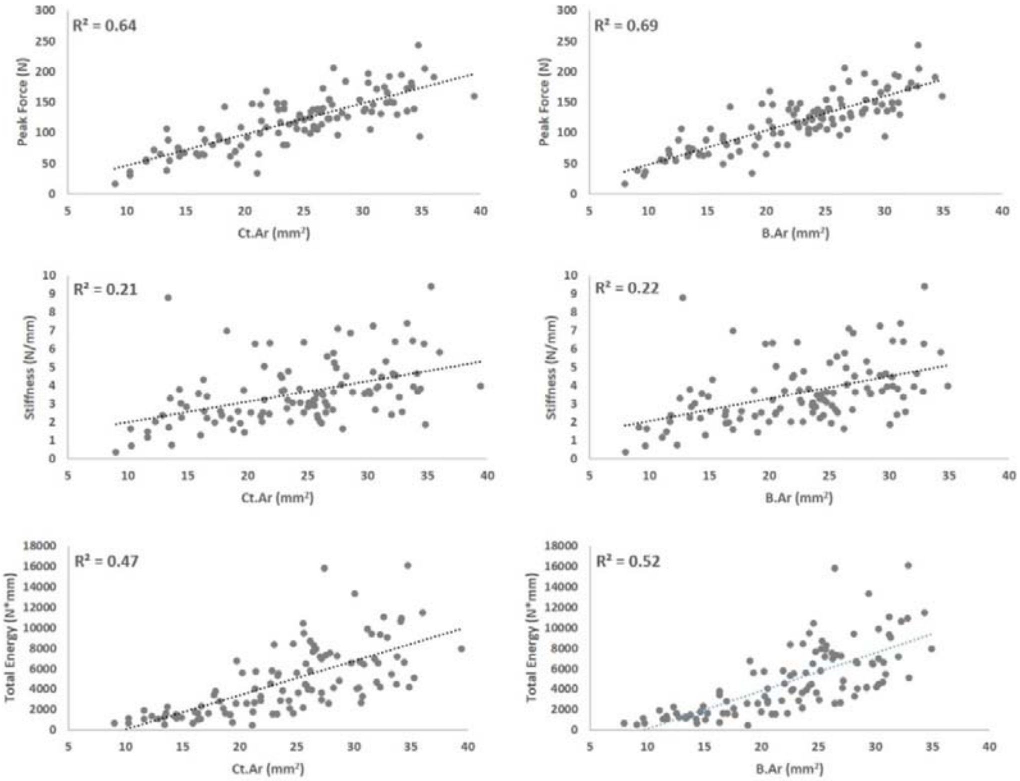

Fig. 1. Plots demonstrating the relationship of the variables peak force, linear structural stiffness, and total energy to fracture to Ct.Ar and B.Ar. B.Ar is marginally better at predicting all variables than uncorrected Ct.Ar.

IV. DISCUSSION

The preliminary findings reported here indicate that B.Ar is a better predictor of rib structural properties than Ct.Ar; however, despite significant differences in area, accounting for intracortical porosity only marginally improves regressions. As such, it is unlikely that such minor improvement warrants the time and labor costs associated with collecting cortical porosity alone for assessing structural properties. In the case of the ribs, endosteal bone loss, which has a directly observable influence on Ct.Ar, may be more meaningful than intracortical bone loss for predicting structural properties. Furthermore, while a reduction in bone due to increased intracortical porosity by itself may not meaningfully influence structural response to loading, these results do not preclude the use of porosity combined with other microstructural variables in the potential development of a multivariate model to study the effect of said variables on both structural and material properties. Future research will examine the potential influence of other histomorphometric variables on the rib's material properties.

V. REFERENCES

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