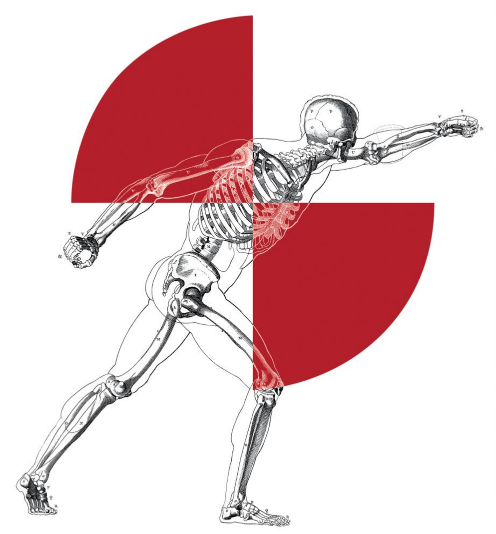

Geometric Properties of the Human Rib: Application in injury biomechanics research

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INTRODUCTION

- An increasing amount of deaths are attributed to traumatic injury of the thorax in motor vehicle crashes (Kemper et al 2007). Accurate finite element models of the human thorax are critical to help researchers determine thresholds of injury for this anatomical region. A key aspect of these models is the precise geometry of the ribs, which has been shown to have a significant impact on the response of the model (Stitzel et al 2003).
- Prior investigations involving rib structure and biomechanics have focused on the middle third of the rib and cortical area (Sedlin 1964; Roberts and Chen 1971). However, findings were limited and difficult to extrapolate to finite element models incorporating whole ribs.
- **The objective of this study is to quantify inter- and intra- individual variation in cross sectional geometric rib properties. Specifically, the predictive ability of external properties will be tested.**

METHODS

- 109 middle ribs from 43 fresh post-mortem human subjects (60 ± 26 years, 10 female, 33 male) were impacted in a dynamic bending scenario. Sections were removed at the variable locations of fracture to explore the ability of external rib geometry, Total Area (Tt.Ar), to predict internal geometry, Endosteal Area (Es.Ar), between individuals.
- One rib from the impacted sample was investigated further by taking sections at 10% intervals along the rib length (Subject A). Two additional non-impacted ribs (elderly males) were sectioned at 25, 50, and 75% of rib length (Subjects B & C). This sub-sample is used to explore the predictive ability of Tt.Ar within individuals.
- Ribs that fractured in two locations during testing were also studied in detail since multiple sections were removed. The ratio Es.Ar/Tt.Ar from Section 1 was used to predict the Es.Ar at Section 2 using the known Tt.Ar at Section 2 and vice versa. Percent error was calculated by comparing the predicted Es.Ar to the measured Es.Ar at both locations.
- All rib thin-sections were prepared using standard histological procedures. Cross-sectional microscopic images were obtained at 40x magnification and measurements were taken in CellSens Dimension imaging software (Figure 1).

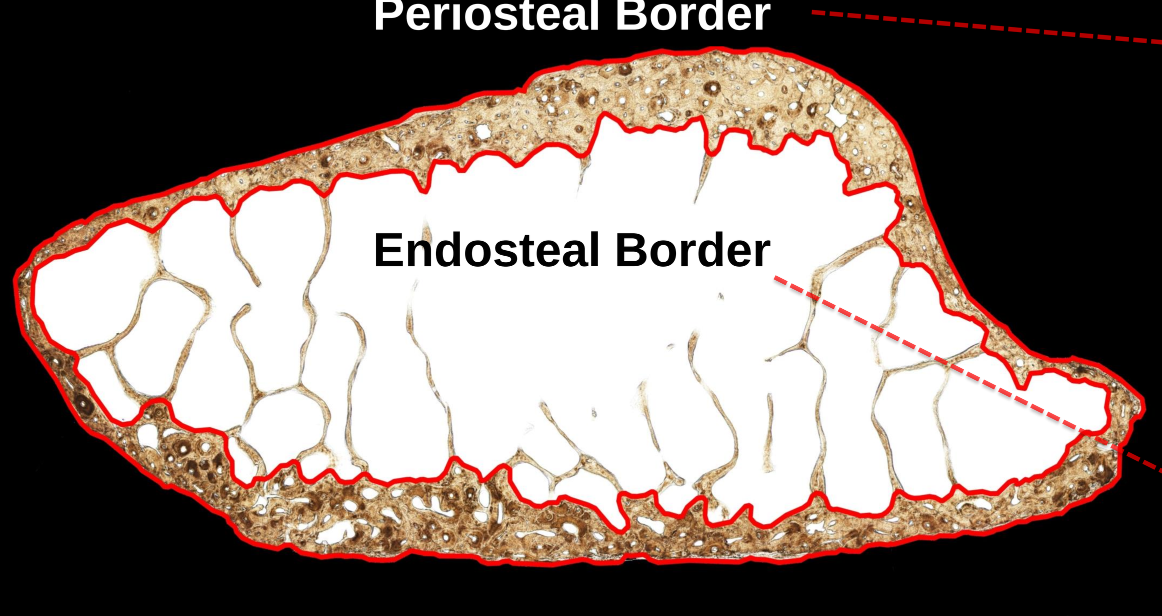


Fig. 1a. Example of rib cross-section with cortical boundaries defined (Subject A)

Fig. 1b. Tt.Ar of cross-section

Fig. 1c. Es.Ar of cross-section

RESULTS & DISCUSSION

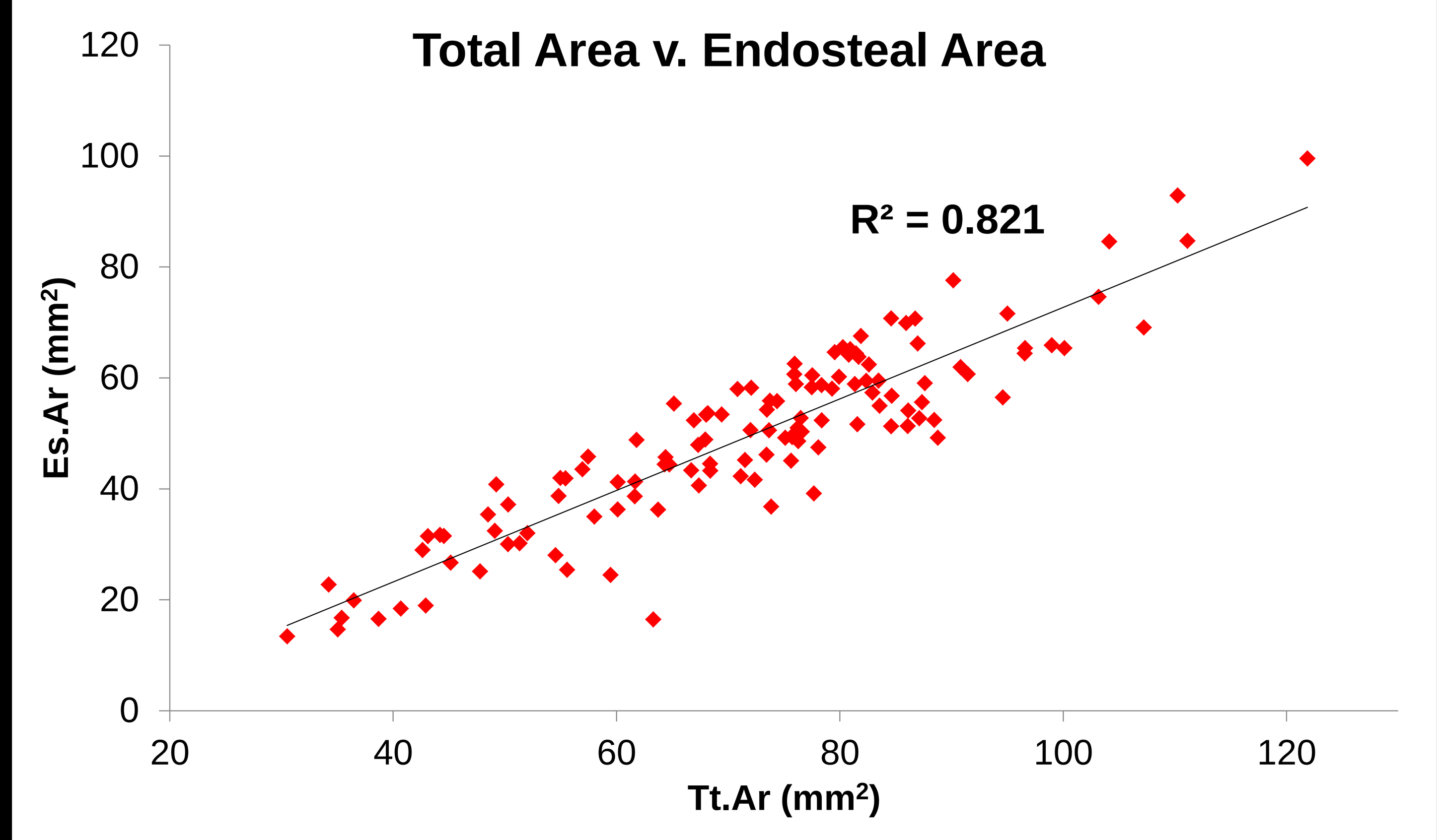
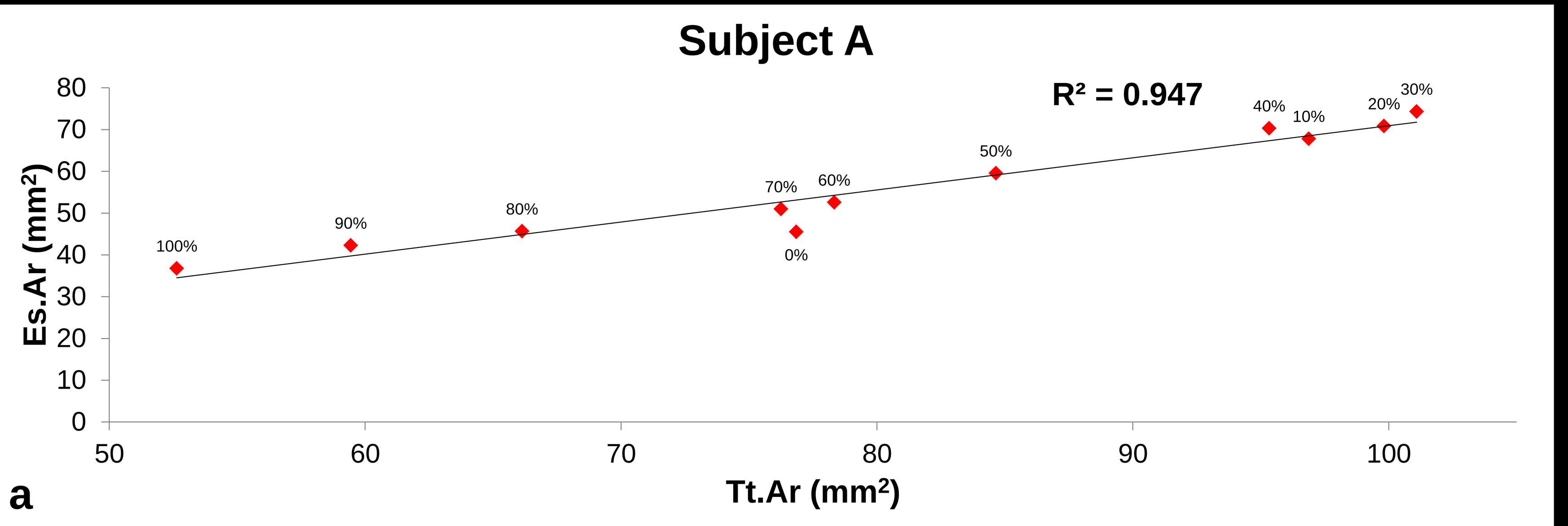
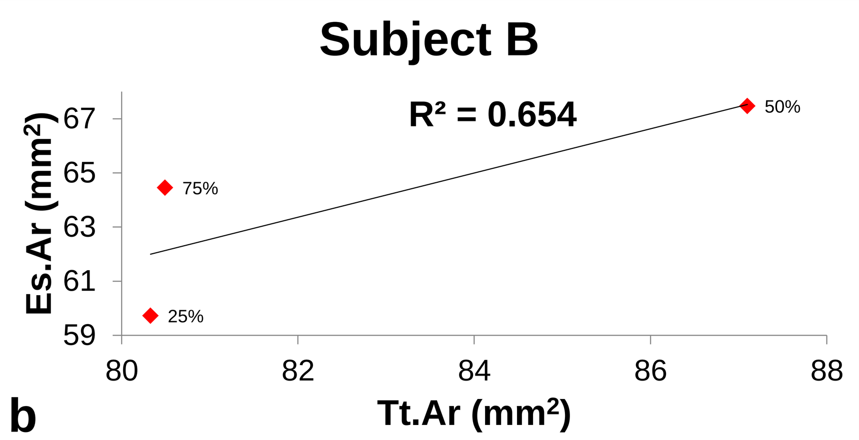


Fig. 2. Linear regression of Total Area to Endosteal Area for entire sample of impacted ribs at fracture site (n=109)

- Fig. 2. indicates the predictive capability of Tt.Ar at any location along the rib in a sample of ribs from 43 individuals. Sedlin (1964) found a similar trend. Additionally, he investigated the effects of age on this relationship between geometric properties, which is a future goal of this study.
- Although the geometry of the rib changes drastically from the posterior (Fig. 3a.) to the middle (Fig. 3b.) to the anterior (Fig. 3c.) in a single rib, the relationship between Tt.Ar and Es.Ar remains constant in one example (Fig. 4a.). However, this relationship is less consistent in others (Fig. 4b,c).
- Roberts and Chen (1971) reported that Cortical Area (Tt.Ar-Es.Ar) remained constant along the length of the rib, particularly in the midshaft, which is consistent with the strong relationship between Tt.Ar and Es.Ar seen in Fig. 3a. These findings applied to ribs 1-8 of an individual. The effects of rib level need to be explored further in the current study.

Fig. 3a-c. Rib cross-sections from Subject A at a) 20% b) 50% and c) 80% of the total rib length





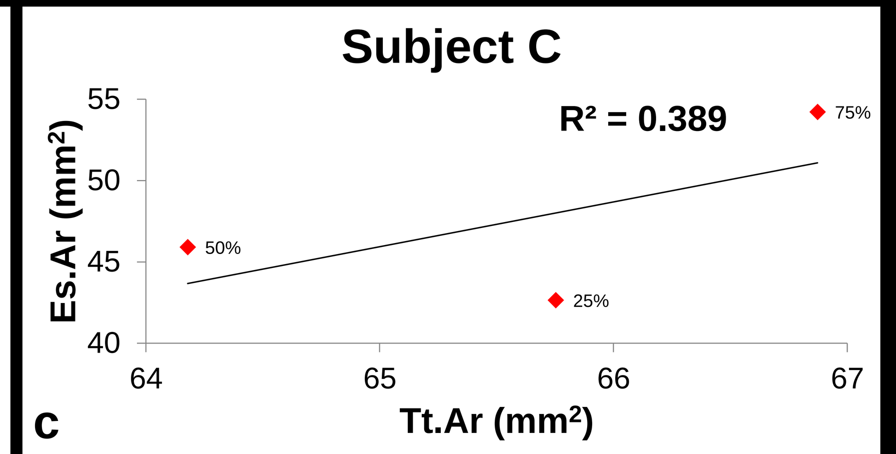


Fig. 4a-c. Total Area (Tt.Ar) versus Endosteal Area (Es.Ar) of the left 7th rib of 3 elderly males

- When comparing two random locations within a rib, the predictive ability of Es.Ar from Tt.Ar varies (Fig. 5). Although the known ratio of Es.Ar/Tt.Ar at one location was able to predict Es.Ar at a second location with percent errors typically under 10%, some cases had errors up to 50%. Fig. 5 also reveals that there was usually more error in predicting Section 1 Es.Ar from the ratio obtained at Section 2. Since Section 1 was always more posterior than Section 2, this indicates that more posterior portions are better at predicting the geometric properties of more anterior sections of the ribs than vice versa.

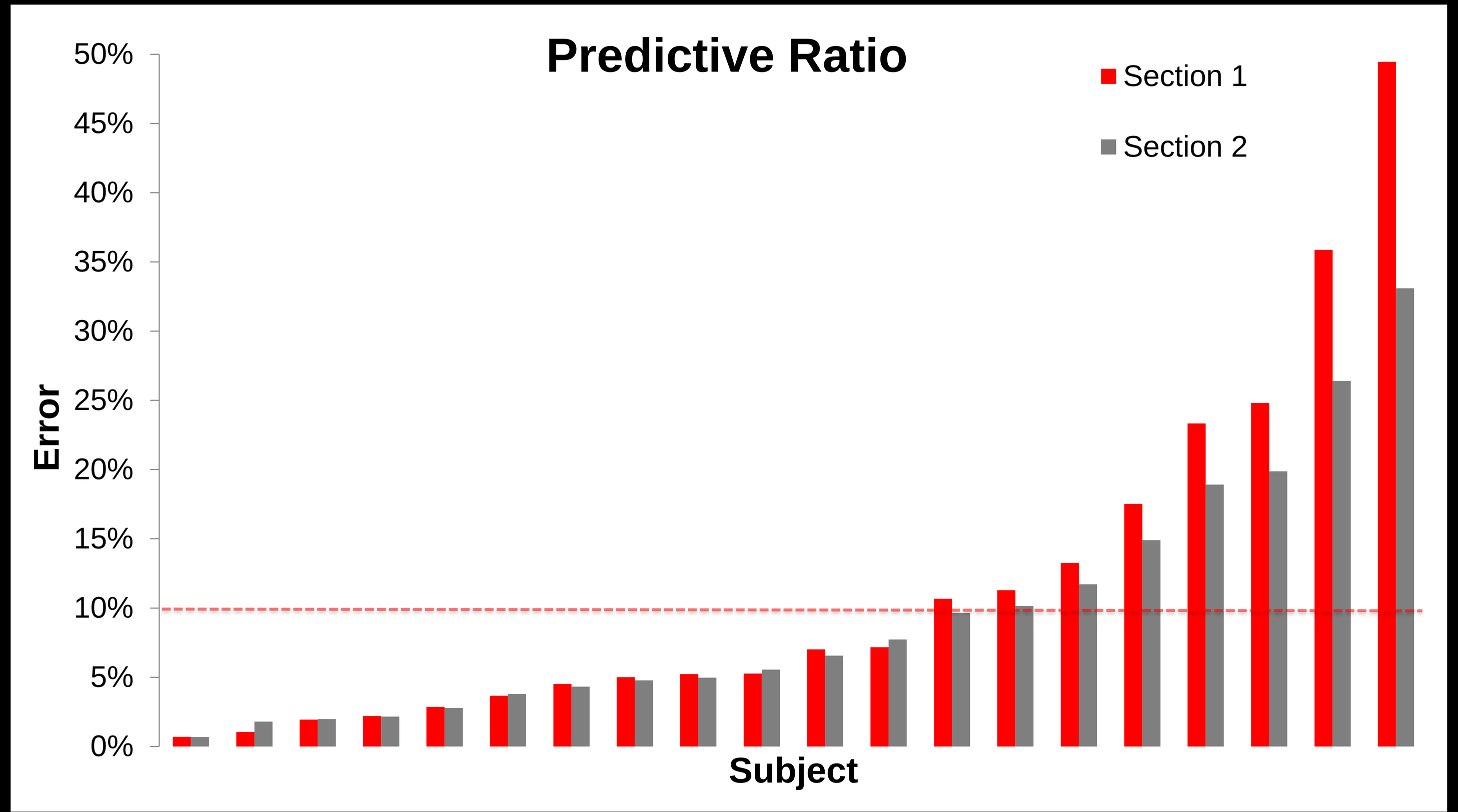


Fig. 5. Use of known ratio, Es.Ar/Tt.Ar, at one section to predict Es.Ar at a second section within a rib

CONCLUSIONS

- This study demonstrates the predictive ability of rib external geometry (Tt.Ar). However, further investigation is necessary, and future work will explore possible reasons for the extreme variation seen in the efficacy of the ratio.
- Use of these data can significantly improve modeling efforts. Geometric variables (e.g., cortical thickness and area) are critical aspects necessary to ensure proper response of finite element models of human ribs and thoraces (e.g., Fig. 6).

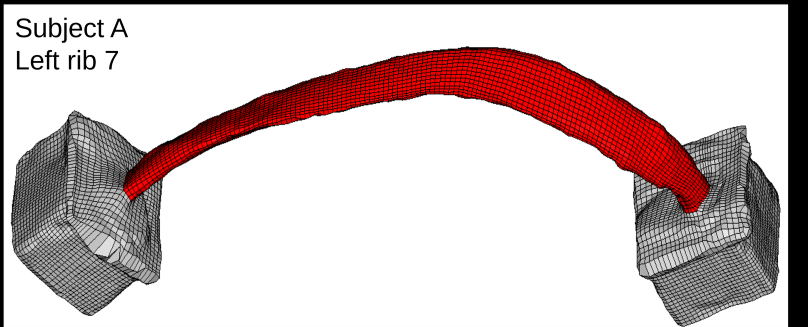


Fig. 6. Example of finite element mesh of rib

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