Comparison of Individual Rib Cage Shape Variation with Regression Predictions

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I. INTRODUCTION

Thoracic injuries from blunt impact, such as rib fractures caused by motor vehicle crashes, are linked to higher morbidity and mortality [1]. In recent studies, injury risk in vehicle crash has been shown to be elevated for females, older individuals, and heavier individuals [2]. In addition to local biomechanically relevant features, such as material properties and cortical bone thickness, global variations in rib cage shape may also contribute to differences in injury tolerance. Morphological techniques and statistical shape models have been used to characterize and predict the average geometric properties of individual ribs and whole rib cages from a given set of demographic parameters [3-5]. While state of the art, these studies may be limited in sample size when considering the full rib cage and the predicted shapes do not account for geometries beyond average. The objective of the current study was to quantify the variation in real world rib cages from a large sample of adult individuals within the same demographic criteria by comparison of individual variation to regression predictions of rib cage shape.

II. METHODS

This work was completed using data from a retrospective study of 2,250 chest/abdomen/pelvis clinical CT scans obtained from patients of Atrium Health Wake Forest Baptist Hospital between 2016 and 2023 under #IRB00006511. An ML-based segmentation tool [6] was used to automatically segment the rib cage and sternum, and ten measurements of whole rib cage shape, covering linear, areal, volumetric, and angular measures, were collected from each scan using custom MATLAB code. Multivariate multiple regression was performed to evaluate how subject age, sex, stature, and weight predict the rib cage measurements. This dataset was used to examine the unique phenotypes of rib cages seen within a narrow range of height and weight criteria representative of small females, average females, and average males. The National Health and Nutrition Examination Survey [7] aggregated from 2013-2016 [8] was used to define stature and weight criteria describing the 5th percentile female (F05), 50th percentile female (F50), and 50th percentile male (M50). Subjects meeting these percentiles ± 5 percent were selected and compared to their regression predictions, using the average height and weight of the subjects as regression inputs. The results for the rib cage measurements with the highest R^2 values in each category are presented.

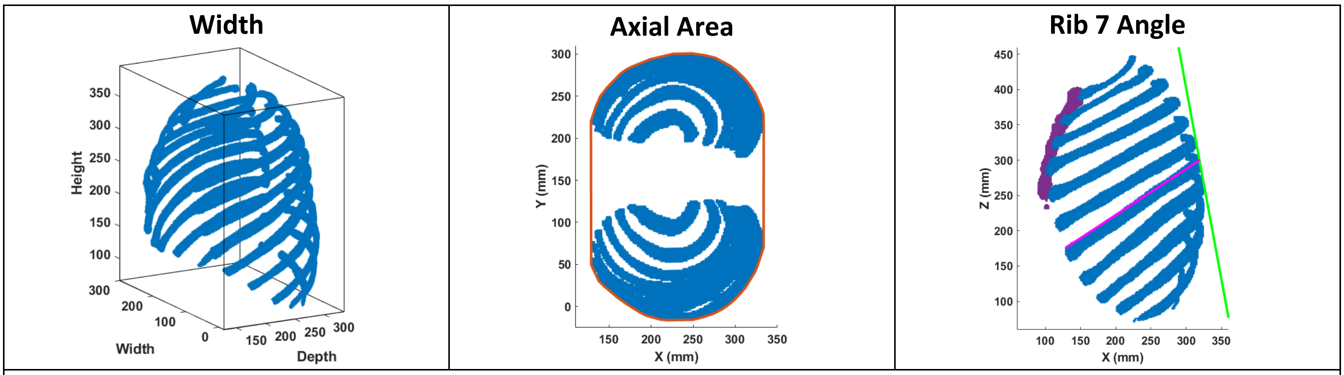

Figure 1. Depiction of rib cage measurements analyzed in this study. Rib cage volume not pictured.

III. INITIAL FINDINGS

In the study, six females fulfilled the F05 criteria, defined by height ranges of 1.30 to 1.53 m and body weight ranges of 32.3 to 54.3 kg. Similarly, five females and thirteen males met the 50th percentile criteria for their

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respective sexes, with height ranges of 1.61 to 1.63 m and 1.75 to 1.77 m, and body weight ranges of 70.7 to 75.5 kg and 84.0 to 89.1 kg, respectively. Figure 2 shows a comparison of the range of measurements seen in each subpopulation to their respective regression prediction. The regression predicts the mean measurements of all three subpopulations with a mean deviation of 5% or less. As indicated by the bar graphs, the regression prediction is farthest away from the maximum measurement values, and deviates by 12.1%, 12.6%, and 21.2% on average for F05, F50, and M50, respectively. Figure 2E highlights the difference in rib cage height, rib angle, and depth between two F05 subjects.

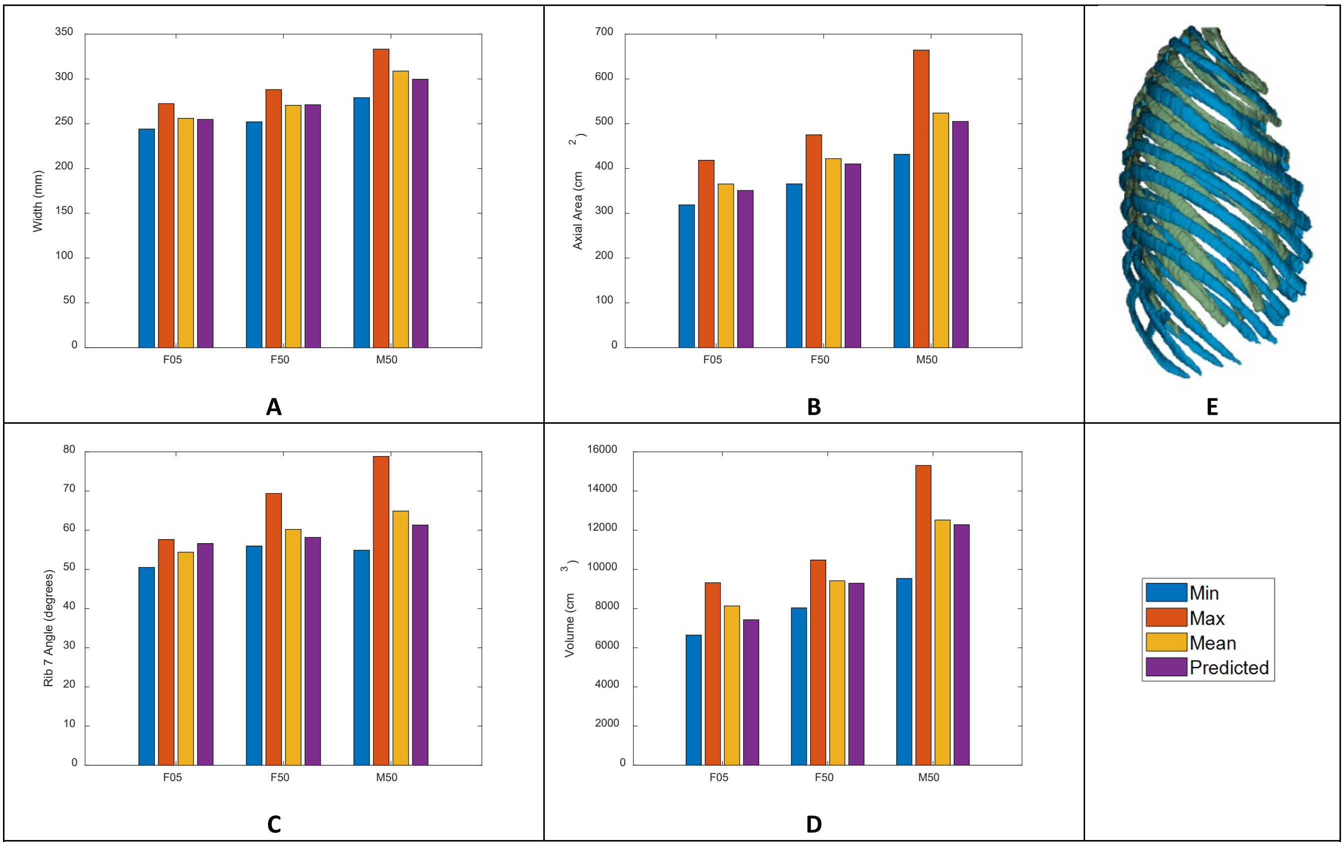

Figure 2. Min, max, and mean of subpopulations compared to regression predictions for A. Width, B. Axial Area, C. Rib 7 Angle, and D. Volume. E. Lateral view of the two small female rib cages that are most different from each other in all 10 measurements.

IV. DISCUSSION

This study highlights the limitations of solely using predictive models to capture changes in rib cage shape. This analysis demonstrates that individuals sharing similar demographic characteristics can show considerable variation in their placement within the rib cage distributions collected from a large sample size. While this work only includes F05, F50, and M50, the same analysis can be applied to any demographic of interest. Future work will include a categorization of rib cage phenotypes (i.e. slim and straight vs tapered) as well as implementation of select rib cage geometries into models to assess the influence on model injury prediction based on holistic shape variation alone.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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