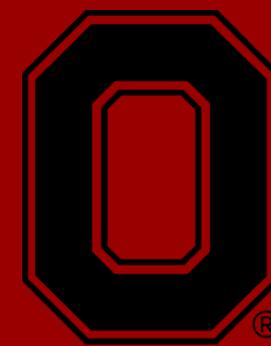


# Analysis of Human Rib Fracture Mode

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## INTRODUCTION

- Traumatic thoracic events are common occurrences that may involve injury to vital organs. Reconstruction of events contributing to rib fractures is complicated by rib morphology and angle. Still, establishing these events may be imperative in forensic contexts especially when soft tissue is absent. Despite extensive study of rib fractures across anthropological, clinical, and injury biomechanics literature, rib fracture patterns are not yet fully understood (Daegling et al., 2008, Love and Symes 2004).
- Predictions of rib fracture patterns depend on understanding potential correlations between mode of failure with individual characteristics, specifically age and sex. The purpose of this preliminary study was to determine predictability of fracture mode of failure and its potential relation to age and sex through gross skeletal examination. To address this problem, this study sought to answer the following question:
  - Is failure mode in human ribs related to age or sex?

## MATERIALS AND METHODS

- The sample consists of 68 ribs from 50 individuals, between 6 - 99 years old (47 males, 21 females) (Fig. 1). Ribs were obtained from donors through OSU's Body Donation Program and Lifeline of Ohio.
- Complete ribs from head to costochondral junction were excised, cleaned of soft tissue, and the ends were potted in 4x4x3 cm<sup>3</sup> blocks of Bondo in a single plane orientation. Ribs were allowed to reach room temperature prior to testing and kept hydrated with normal saline throughout preparation and testing.
- Ribs were tested in a custom pendulum fixture simulating a dynamic (1-2 m/s) frontal (i.e., anteroposterior) impact to the thorax, in which the sternal end of the rib was pushed towards the vertebral end in a bending scenario, putting the cutaneous cortex in tension and the pleural cortex in compression. The two potted ends of the rib were allowed to freely rotate during the impact. See Agnew et al. (2015).
- All ribs were photographed post-impact on both pleural and cutaneous surfaces and placed into one of six fracture modes (Fig. 3). Chi-square tests were performed to analyze the potential relationship between fracture mode and age/sex.

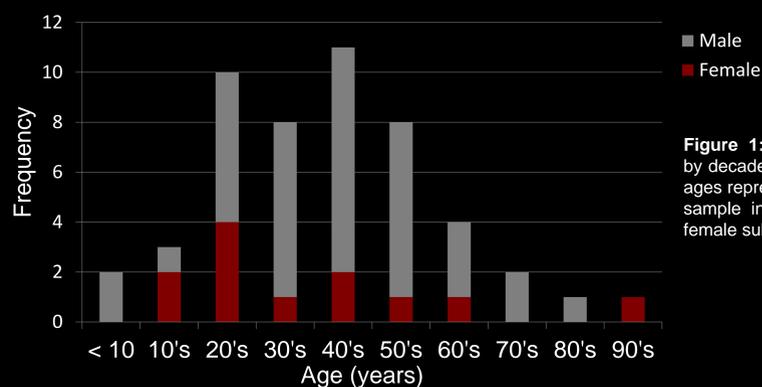


Figure 1: Frequency of subjects by decade, illustrating the range of ages represented in this study. The sample includes more male than female subjects.

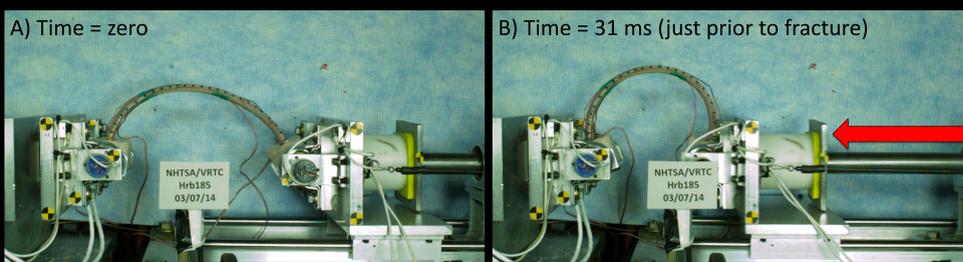


Figure 2. Experimental fixture and set-up for a representative test. A) The rib is positioned pre-impact. B) A 54 kg pendulum drives the shaft and subsequently the sternal rib end towards the fixed vertebral end (red arrow) in the primary loading direction (X), mimicking a frontal impact to the thorax.

### REFERENCES CITED

Daegling D.J., et al. 2008. Structural analysis of human rib fracture and implications for forensic interpretation. J Forensic Sci 53 (6):13 01-1307. Love J.C., Symes S.A. 2004. Understanding rib fracture patterns: incomplete and buckle fractures. J Forensic Sci 49 (6): 1-6. Agnew A.M., et al. 2015. The effect of age on the structural properties of human ribs. J Mech Behav Biomed Mater 41: 302-314.

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## RESULTS AND DISCUSSION

83 total fractures were divided into six fracture modes:

- Transverse\***: perpendicular to the long axis with superior to inferior orientation
- Oblique\***: superolateral to inferomedial orientation or inferomedial to superolateral orientation
- Butterfly\***: transverse fracture that terminates as two oblique fractures
- Buckle\***: incomplete fracture on pleural surface

- Oblique + transverse\*\***: oblique fracture on pleural surface, transverse fracture on cutaneous surface
- Multiple fractures**: more than one complete fracture

\*Definitions based on Love and Symes 2004  
\*\*Definition based on Daegling et al. 2008

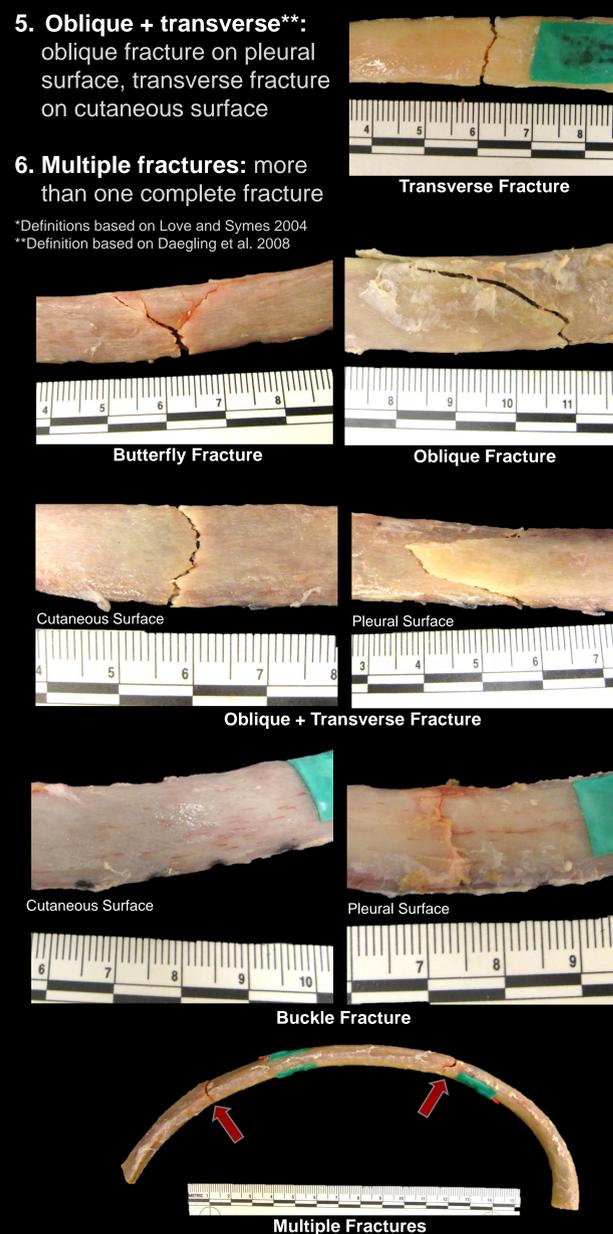


Figure 3: Representative photographs of each of the six fracture modes.

### Is age related to fracture mode?

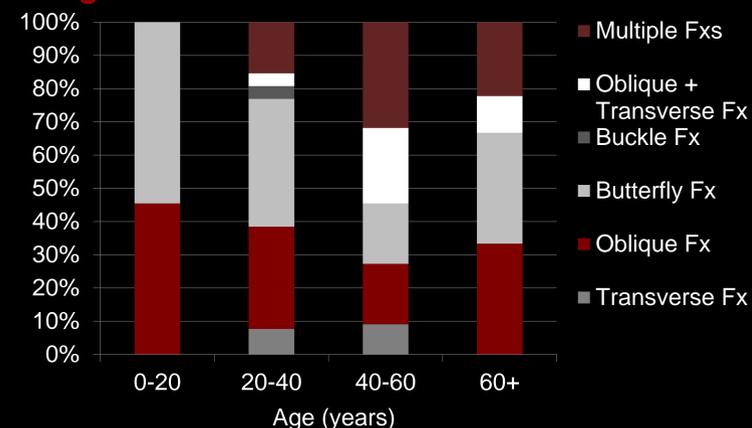


Figure 4: Percentage of rib fracture mode of failure in each broad age category. Sample sizes within each age category were not equal (0-20 n = 11, 20-40 n = 26, 40-60 n = 22, 60+ n = 9).

- It was expected that transverse fractures would be overrepresented in the older age categories due to age-related changes in rib material properties. While transverse fractures were only present in individuals > 30 years old, they were absent in the 60+ age category.
- It was also expected that buckle fractures would be observed in the younger age groups, particularly those under 10 years. However, the only buckle fracture observed occurred in a 22 year old.
- A chi-square test found no relationship between fracture mode and age,  $X^2$  (df = 15, N = 68) = 18.13 (p = 0.256).

### Is sex related to fracture mode?

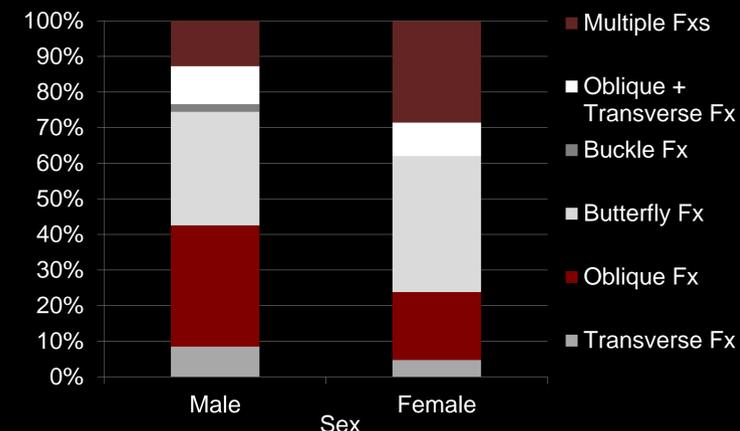


Figure 5: Percentage of rib fracture mode of failure within each sex. Sample sizes within each age category were not equal (males n = 47, females n = 21).

- It was expected that transverse and/or multiple fractures would be observed more frequently in females, particularly older females due to age-related changes in material properties. While multiple fractures were more common in females, there was no clear relationship to age.
- A chi-square test found no relationship between fracture mode and sex,  $X^2$  (df = 5, N = 68) = 3.22 (p = 0.666).

## CONCLUSIONS

- The lack of relationship between either sex or age and fracture mode prompt further examination into why these differences were not reflected in this preliminary study. Future research will consider other factors that may affect the mode of fracture including geometric properties (e.g., curvature and cortical area) in addition to measured structural and material properties (e.g., peak force, displacement, and stress).
- Limitations of this study include unequal representation of ages and sexes. The experimental bending scenario does not account for anatomical rib angle and is therefore an oversimplification- results may not properly reflect real rib fracture mechanisms.

### ACKNOWLEDGEMENTS

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