Variance in Fracture Location of Human Ribs Subjected to Dynamic Antero-Posterior Bending

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I. INTRODUCTION

Thoracic injuries, especially rib fractures, are associated with high mortality rates and are one of the most common injuries in motor vehicle crashes (MVCs) in the Unites States [1-2]. In order to understand the dynamic response of the thorax, it is prudent to analyze mechanical properties of ribs from a sample with large population variation. Studies have shown that fracture characteristics vary, even within the same controlled loading conditions [3-6]. The effect of age, sex, and body size on human rib structural properties have previously been investigated [3-4], but these studies do not include relationships with fracture characteristics. Previous studies have demonstrated trends in frequencies of rib fracture locations [4-5]; however, no variables have been definitively linked to the location of fractures. Furthermore, while presence of fractures is often predictable in finite element models, their location and contributors to determination of that location is more difficult to target [7]. The aim of this study is to identify whether relationships exist between fracture location and subject demographics, as well as individual rib size and measured structural properties.

II. METHODS

Two-hundred fifty-nine human ribs were loaded to failure in an identical dynamic (2 m/s) bending test designed to simulate a frontal thoracic impact (see [3] for further experimental details). Forty-four ribs fractured in multiple locations, so were excluded from this preliminary analysis, leaving a sample which consisted of ribs with only one fracture (n = 215). This sample represents ribs from 130 individuals (males n = 89; females n = 41) ranging in age from 6 – 108 years old with a mean age of 56 ± 23 years. Subject level variables (age, sex, stature) and individual rib size including the total curve length (Cv.Le) and end-to-end span length (Sp.Le) of the rib, were documented. Additionally, rib structural properties were calculated as defined in [3]: percent displacement in the primary loading direction (δ_X), peak force (F_{peak}), total energy (U_{tot}), and linear structural stiffness (K). All of these variables were utilized for comparisons with fracture locations. Fracture location was measured as mean distance from the vertebral rib end and is reported as a percentage of the total Cv.Le of the rib, with 0% at the vertebral end and 100% at the sternal end. Pearson correlation analysis was used to determine if a relationship exists between fracture location and each of age, stature, Cv.Le, Sp.Le, δ_X, F_{peak}, U_{tot}, and K.

III. INITIAL FINDINGS

Fracture location frequencies by sex are presented in Fig. 1. Fractures occurred primarily in the anterior and anterolateral regions of the ribs (60-90% of rib length) for both males and females. Pearson correlation results are shown in Table I. Age, stature, Cv.Le, Sp.Le, and U_{tot} were found to have insignificant relationships with fracture location (p = 0.127 – 0.917), while significant relationships (p = 0.001 – 0.032) were found for δ_X, F_{peak}, and K (Figure 2).

TABLE I
PEARSON CORRELATION *(R) VALUES AND P-VALUES*

		Age	Stature	Cv.Le	Sp.Le	δ_X	F_{peak}	U_{tot}	K
Fracture Location	*r*	-0.014	0.068	0.007	0.056	-0.231	0.147	-0.105	0.183
	p	0.837	0.328	0.917	0.414	**0.001**	**0.032**	0.127	**0.008**

*significant p-values are shown in **bold**

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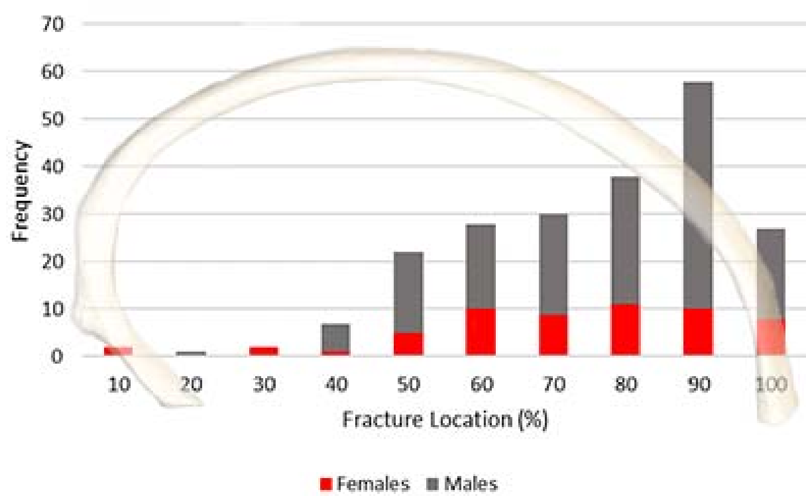

Fig. 1. Fracture location frequency.

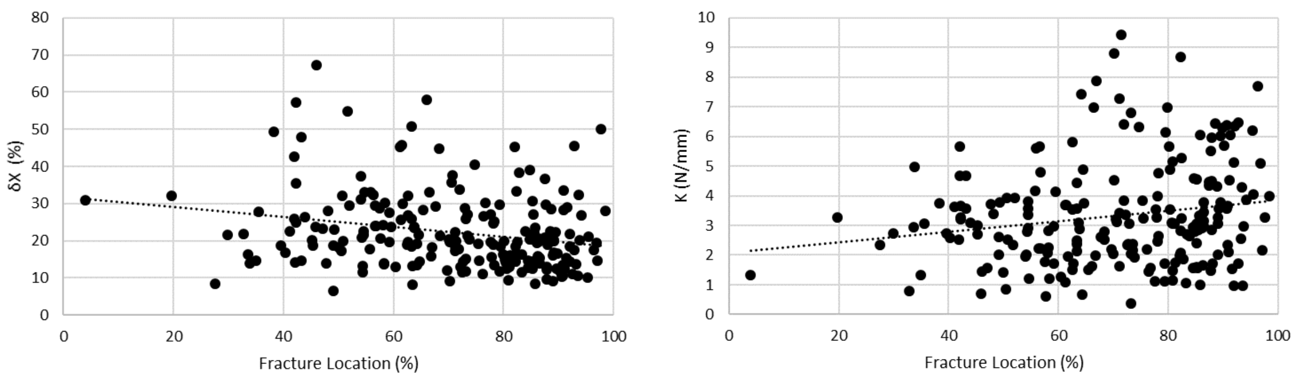

Fig. 2. Scatterplots with best fit lines for fracture location with percent displacement (δ_X; left) and stiffness (K; right).

IV. DISCUSSION

The high frequency of fracture locations in the anterior and anterolateral regions of the ribs is consistent with findings in other structural rib and thoracic experiments [5-6][8]. By demonstrating that age, sex, and stature have no relationship with fracture location, future research can eliminate subject demographics in predictive models. Significant relationships were found between fracture location and δ_X, F_{peak}, and K, however they are weak. The strongest correlation was found between % displacement and fracture location (r = 23%), and this is intuitive since both are likely due to the bending behavior of the rib during impact. Future work will explore elastic and plastic rib response and will also focus on examining any correlations between fracture location and more complex causative variables, e.g., gross and cross-sectional rib geometry, as well as interactions between these rib-specific measurements.

V. REFERENCES

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