Biomechanical Response Corridors of 50th Percentile Female Human Ribs in Anterior-Posterior Loading

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I. INTRODUCTION

In motor vehicle crashes (MVCs), females tend to be at greater risk of thoracic injuries than males [1-2]. Among these thoracic injuries, rib fractures are the most common, and they have not been effectively reduced even with newer year vehicles in frontal collisions [3]. Rib fractures can be mitigated by enhancing vehicle safety, which requires biofidelic safety tools, such as anthropomorphic test devices (ATDs) and human body models (HBMs). While small female (5th percentile) ATDs and HBMs have been developed and evaluated [4-5], few efforts have focused on the mid-size female (50th percentile) [6-7], making it difficult to evaluate injury risk for all female occupants. Ideally, large datasets collected from experiments using human volunteers and post-mortem human subjects (PMHS) are utilized, but unfortunately, very limited female biomechanical data exist in the literature, such that improving ATD and HBM thoracic biofidelity for female populations is challenging, even for the small female. A recent study reported biomechanical response corridors of human ribs in various populations including small females, but did not include mid-size females [8]. Therefore, the objective of this study was to generate a human rib dynamic frontal impact response corridor for the mid-size female and compare it with those from the mid-size male and small female.

II. METHODS

Body size for the mid-size female (50th ± 10th: height of 161.8 ± 2 cm, weight of 62.3 ± 3.6 kg) was defined using previously published body size categories for Hybrid III ATDs and HBMs [9]. Thirty mid-size female ribs from 25 PMHS ranging in age from 41 - 99 years (65 ± 17 years) were tested to failure in a custom fixture that mimics a frontal thoracic impact (anterior-posterior bending) (Fig. 1). Any mid-level ribs (4th – 7th) from PMHS within the defined height *or* weight ranges were included in the biomechanical corridor. Force (F) was quantified using a six-axis load cell (CRABI neck load cell, IF-954, Humanetics, Plymouth, MI, USA). Rib displacement was measured by a string potentiometer (AMETEK, Rayelco P-20A, Berwyn, PA, USA). After data were filtered at 300 Hz, displacements were normalized by rib span length to calculate % displacement (D) for each rib. More detailed information on specimen preparation and experimental set-up can be found in previous studies [10]. In order to generate a mid-size female F-D corridor, data were input to a custom MATLAB code used in the original study [8]. The newly created biomechanical response corridor for the adult mid-size female (50F) was then compared to the mid-size male (50M, age range 42 – 97 years) and small female (5F, range in age from 54 – 84 years) corridors of comparable ages generated from the previous study [8]. Differences in force and displacement at fracture for all three groups were evaluated by analysis of variance (ANOVA) with Tukey's post-hoc tests. In order to assess differences in whole F-D responses between groups, Biofidelity Ranking System Score (BRSS) was also computed [11]. A BRSS = 1.0 indicates that the mean curve for each group is one standard deviation from the other, so a BRSS ≥ 1.0 was used to delineate meaningful differences between rib corridors for each comparison.

III. RESULTS

A biomechanical response corridor for the 50F was generated with mean (1SD) of force and displacement at fracture of 71.7N (33.0) and 20.5% (10.0), respectively (Fig. 2). No differences in displacement were found between any of the three groups (ANOVA, $p = 0.692$, Fig. 3), while force showed a significant increase from the small female ribs to the mid-size male ribs (ANOVA, $p = 0.001$, Fig. 4). Tukey's post-hoc analysis showed the force for the 50M ribs was significantly larger than both 50F ribs ($p < 0.001$) and 5F ribs ($p = 0.001$), while no difference in force was found between 50F and 5F ribs ($p = 0.353$). However, the BRSS between 50F ribs and the other two groups were all ≥ 1, indicating meaningful differences between all groups (Fig. 2).

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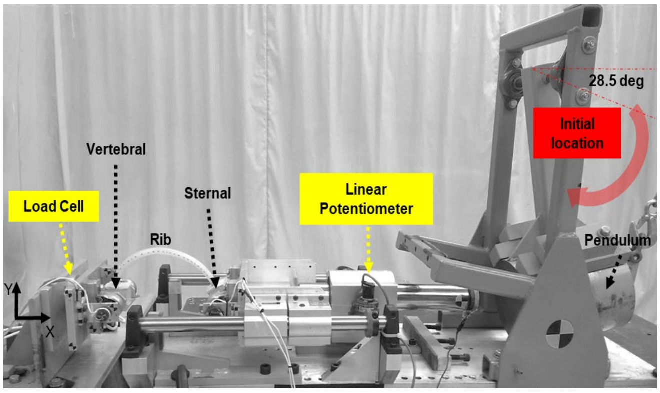

Fig. 1. A general experimental set up (adapted from [10]). A pendulum (54.4 kg) was released to generate a 2m/s impact velocity.

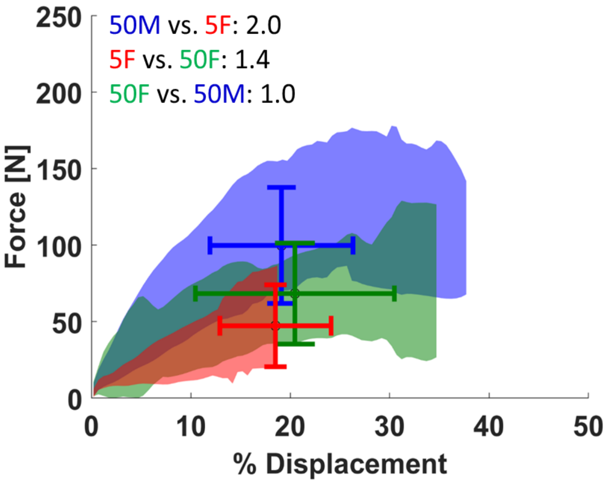

Fig. 2. Mid-size female (50F, green, n=30), mid-size male (50M, blue, n=84), and small female (5F, red, n=7) corridors. 2D error bars represent mean ± 1SD of FR and D. Average BRSS are provided.

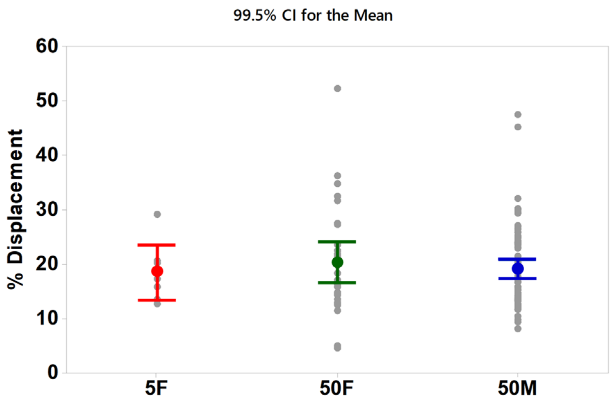

Fig. 3. Rib displacement at fracture for small female (5F), mid-size female (50F), and mid-size male (50M).

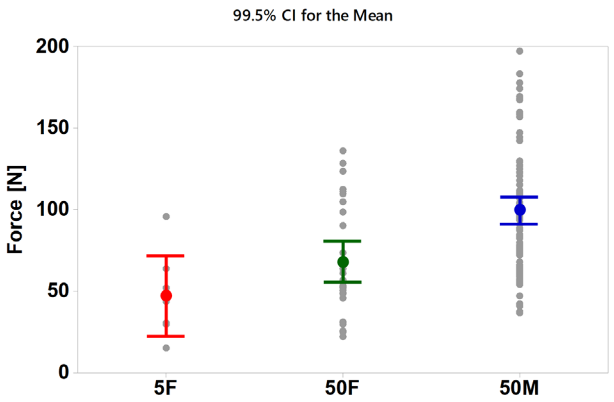

Fig. 4. Rib force at fracture from small female (5F), mid-size female (50F), and mid-size male (50M).

IV. DISCUSSION

Although 5F data showed large confidence intervals due to the limited sample size (n=7), results revealed that female ribs (50F and 5F) resisted less force prior to fracture than 50M ribs, supporting the finding of greater thoracic injury risk to females than males seen in real-world frontal MVCs [1][12]. Similar differences in force measured in three point bending of human ribs were found when females were compared to males [13]. However, when rib cortical coupons were tested, no significant differences in material properties between sexes were found [14]. This implies that rib global and cross-sectional geometry could be key parameters that possibly explain differences in structural F-D corridors between sexes. Further investigation should be focused on identifying the precise sources of variation leading to differences in sex-specific biomechanical response corridors in order to enhance current and future safety tools, e.g., ATDs and HBMs.

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VI. REFERENCES

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