Investigation of Repeat Anterior-Posterior Loading of Human Ribs

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Abstract:

Thorax injuries are common in motor vehicle crashes, leading to high morbidity and mortality rates. Quantifying variation in rib response and fracture risk for all occupants during frontal impacts is crucial in advancing injury prevention measures. While many studies have been conducted on single impacts of ribs, efforts in understanding why some ribs do not fracture upon impact are lacking. Furthermore, few studies have explored structural property changes during repeat loading in human ribs. The goal of this study was to evaluate differences in structural properties between multiple impacts to the same rib.

Three-hundred and forty-seven ribs from 182 post-mortem human subjects (59 females, 123 males, 4-108 years) were dynamically impacted in anterior to posterior loading detailed in Agnew *et. al* (2018). A 6-axis load cell, linear string potentiometer, and uniaxial strain gages measured force, displacement, and strain, respectively. A custom MATLAB code was used to calculate structural properties. Ten ribs did not fracture during initial impact, and were impacted again. Differences in structural properties between first and second impacts were quantified with consideration for variation in impact velocity (1m/s vs 2m/s) and whether they failed during the second impact. Additionally, ribs that did not fail were compared to the larger subsample that did fail on first impact (n=336).

Total energy decreased between first and second impacts for all ten ribs. Peak force, force at yield, and linear structural stiffness were generally reduced after the first impact in most cases. No clear differences were observed for % displacement (peak or yield) or peak strain between repeated tests. Strain rate decreased by approximately 0.1 strain/s when both impacts occurred at 2m/s. Age was found to be significantly lower in the ribs that did not fail (4-30 years) compared to those that did. Age- and sex-matched samples from ribs that failed during initial impact were compared with ribs that did not fracture. Peak force and stiffness from the initial impact did not significantly vary between non-fractured ribs and matched fractured samples ($p>0.04$).

These data reveal that additional mechanisms need to be explored to adequately understand effects of repeated dynamic loading to ribs. Differences in cross-sectional geometry such as larger cortical thickness ($p=0.001$) and cortical area ($p<0.0001$) were found for the ten non-fractured ribs when compared to age- and sex-matched fractured samples. These geometric differences likely contributed to increased fracture resistance, and the possible accumulation of microdamage may explain why ribs tend to show decreases in structural response (especially

for yield) during subsequent impacts. Understanding these complex loading mechanisms can aid in quantifying rib response variation when modeling a large range of occupants.

Repeated dynamic testing of whole human ribs has not previously been explored, although quasi-static fatigue loading has been extensively investigated with the goal of being non-injurious. Quantifying changes in rib properties under dynamic injurious repeated loading is important to characterize differential fracture risk in order to make advancements to prevent occupant thoracic injuries.