A121 Variation in Human Rib Failure Mechanisms in Experimental Anterior-Posterior Loading

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Learning Overview: After attending this presentation, attendees will have an appreciation for interdisciplinary research in skeletal trauma analysis, specifically in human ribs. Attendees will learn how to interpret failure mechanisms (i.e., tension vs. compression) in human ribs via strain data and high-speed video.

Impact on the Forensic Science Community: This presentation will impact the forensic science community by demonstrating the need for interdisciplinary analyses of skeletal trauma in ribs. Increased understanding of how ribs fail in an anterior-posterior bending scenario will serve to improve skeletal trauma analyses in forensic anthropology.

Rib fractures are of significant clinical, forensic, and biomechanical interest, yet the biomechanics of rib fractures, specifically the mechanism of failure, is incompletely understood.[1-5] Rib fractures are associated with traumatic events, including accidents and homicides, and a more thorough understanding of the failure mechanism, through validated, experimental trauma research, could lead to increased accuracy in re-creating traumatic events and provide support for scientific testimony.[6] Bone is generally known to be weaker in tension than compression; however, previous studies have found that ribs failed more frequently in compression rather than in tension.[5] This study aims to determine whether the failure mechanism of human ribs, when loaded in precisely the same manner, is predictable.

Sixty-nine human ribs (14 female, 55 male) from 32 Postmortem Human Subjects (PMHS) (11–90 years old, mean=48.3 years) were loaded in an anterior-posterior bending scenario at a dynamic rate of 2m/s. Ribs were each instrumented with four uniaxial strain gauges from Vishay® Micro-Measurement along the longitudinal axis on the cutaneous and pleural surfaces at 30% and 60% of the rib's total curve length. Data directly collected and utilized in this research included: peak strain (microstrain) from strain gauges and time (millisecond). Each experimental test was recorded using a Phantom® VEO 710L high-speed video camera at a minimum of 8,000 frames per second (fps). For a comprehensive description of experimental test details and boundary conditions, see reference.[7]

Strain modes were as anticipated for such a bending scenario; all cutaneous gauges recorded tensile strain (+) and all pleural gauges recorded compressive strain (-). Strain data from the gauges closest to fracture location were used to identify the time of peak strain. Failure mechanism was then determined by quantifying the difference in timing of peak strain between the cutaneous and pleural gauges; whichever gauge reached peak strain earlier revealed the surface on which the bone initially failed and therefore the failure strain mode (tension or compression). Experimental test videos from each impact were viewed frame-by-frame to observe whether the failure initiated on the cutaneous or pleural surface of the bone. In cases where more than one failure occurred, only the initial failure was considered in this analysis. Video data were then compared to strain gauge data to determine whether the data collected from each method were consistent.

The strain gauge data revealed initial failure in tension (n=34) occurring more frequently than in compression (n=29); however, these data also found simultaneous failure in tension and compression (n=6) that was not observed in the high-speed video data. From the corresponding high-speed videos, initial bone failure occurred more frequently in tension than compression (n=43 and n=26, respectively). The consistency rate of the initial failure mechanism between the strain gauge data and high-speed video was only 47.8%, indicating that even video captured at 8,000–12,000fps may not be enough to elucidate failure strain mode (i.e., mechanism).

Overall, results indicate that a definitive statement regarding whether human ribs subjected to anterior-posterior bending always fail in tension or compression cannot be made. Bones, specifically ribs, are complex structures and likely do not respond to loading like other skeletal elements. Whether utilizing strain data or high-speed video data, ribs failed in either tension, compression, or simultaneously in tension and compression. Previous assumptions regarding the consistency of ribs failing in a specified strain mode may be unfounded. Additionally, results demonstrated that the method in which failure was evaluated affected the determination of failure mechanism. Interdisciplinary experimental research is imperative to further investigate failure mechanisms utilizing a hierarchical model (i.e., from the tissue level up to the individual level) in ribs and other skeletal elements.[5]

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