

Failure Tolerance of Male and Female Lower Extremities Under Pure Bending and Combined Loading Modes

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Introduction: Lower extremity injuries remain prevalent in frontal crashes, particularly for female occupants. Previous studies have captured the failure tolerance of mid-size male lower extremities in pure bending and combined loading modes (Kerrigan et al., 2004; Nyquist et al., 1985; Schreiber et al., 1998; Untaroiu et al., 2008), but very few include a significant number of small female specimens.

Objective: This study aimed to characterize the failure tolerance of small female and mid-size male post-mortem human subject (PMHS) lower leg specimens under combined axial compression and posterior-anterior bending moment under the same boundary conditions.

Methodology: Twenty-four lower leg specimens, including tibia, fibula, and surrounding soft tissue, were obtained from 50th percentile male (n=12) and 5th percentile female (n=12) PMHS. Dynamic tests to failure were performed at 1.5 m/s using a test set-up that loads the leg in bending and varying levels of superimposed axial compression (Ivarsson et al., 2009). Transverse load was applied via three-point bending in the posterior-anterior direction with the central load applied at the distal third of the leg. To understand the relationship between transverse load and superimposed axial compression, specimens were tested at varying levels of superimposed axial compression: 0 kN (pure bending) and 2, 4 and 6 kN (combined loading). Additionally, when left and right legs were obtained from the same subject (n=12), the effect of the magnitude of the superimposed axial load was assessed by assigning these paired segments to distinct load conditions. Fracture timing was identified through a combination of force, strain and acoustic sensor data, high-speed video, and post-test CT scan review.

Results: At the time of failure, axial compression force was recorded, and the transverse load was used to compute the external bending moment values. Of the 24 lower leg specimens tested, 17 failed at the tibial shaft under the impactor, 6 failed near the potting interface, and 1 tibia did not fracture. Under pure bending, the mean± standard deviation external moment at failure in the males and females were 255 ± 57 Nm and 156 ± 15 Nm, respectively. At the highest superimposed compressive load (6kN), the average moments at failure were 195 Nm for the males and 72 Nm for the female specimens. Of the matched pairs tested, when superimposed axial load was increased, there was an average 21% decrease in external bending moment at failure.

Conclusions: This study characterized the failure tolerance of small female and mid-size male PMHS leg specimens under consistent pure bending and combined loading conditions. This data can be compared to pre-existing data sets to provide a more comprehensive insight into the failure tolerance of the leg for both mid-size males and small females as well leveraged to develop injury risk functions for the leg complex. Future work includes the use of scaling techniques to normalize the data set and subsequently scale the response across varying anthropometries.

References:

- Ivarsson, B. J., Genovese, D., Crandall, J. R., Bolton, J. R., Untaroiu, C. D., & Bose, D. (2009). *The Tolerance of the Femoral Shaft in Combined Axial Compression and Bending Loading*. 2009-22-0010. <https://doi.org/10.4271/2009-22-0010>
- Kerrigan, J. R., Drinkwater, D. C., Kam, C. Y., Murphy, D. B., Ivarsson, B. J., Crandall, J. R., & Patrie, J. (2004). Tolerance of the human leg and thigh in dynamic latero-medial bending. *International Journal of Crashworthiness*, 9(6), 607–623. <https://doi.org/10.1533/ijcr.2004.0315>
- Nyquist, G. W., Cheng, R., El-Bohy, A. A., & King, A. (1985). Tibia bending: Strength and response. *SAE Transactions*, 94, 240–253.
- Schreiber, P., Crandall, J., Hurwitz, S., & Nusholtz, G. S. (1998). Static and dynamic bending strength of the leg. *International Journal of Crashworthiness*, 3(3), 295–308. <https://doi.org/10.1533/cras.1998.0077>
- Untaroiu, C., Ivarsson, J., Genovese, D., Bose, D., & Crandall, J. (n.d.). *BIOMECHANICAL INJURY RESPONSE OF LEG SUBJECTED TO COMBINED AXIAL COMPRESSIVE AND BENDING LOADING*.