Investigating Deviations from Expected Fracture Patterns in Human Tibiae loaded in 4-point Bending

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Introduction:

Understanding fracture variation under equivalent loading conditions is essential for enhancing biomechanical models, safety assessments, and protective measures in automotive, military, and sports applications. While midshaft wedge fractures are typically expected from bending loads, real-world and experimental data often deviate from this pattern. Without identifying the factors influencing these deviations, injury prediction models may produce inexact outcomes, leading to suboptimal injury prevention or severity reduction strategies. Therefore, this study quantifies fracture deviations, examines contributing factors, and explores methods for refining injury models.

Objective:

1) Quantify fracture frequency based on fracture type, location, and number relative to the expected outcome of a single midshaft wedge fracture under 4-point bending load
2) Identify demographic, morphological, and experimental boundary condition trends in tibiae with atypical (non-wedge) fractures

Methodology:

Ninety tibiae obtained from postmortem human subjects (n= 60) were tested in 4-point bending at 40% and 60% of their length to simulate pedestrian impacts to the leg. Experimental conditions included lateral-medial impact direction at 6 m/s (n=60), lateral-medial at 2 m/s (n=10), posterior-anterior at 2 m/s (n=10), and posterior-anterior at 6 m/s (n=10). Fractures were classified using the AO/OTA system. Tibiae were categorized into four groups designed around the expected outcomes of fracture type, fracture location, and number of fractures: (A) Wedge, Midshaft, One, (B) Wedge, Midshaft, >1, (C) Wedge, Not Midshaft, One, and (D) Non-Wedge, Any, Any. Group D (outliers of expected outcomes) were subsequently analyzed for demographic, morphological, and experimental factors influencing atypical fracture patterns.

Results:

Among 90 tibiae, 62% (n=56) exhibited at least one wedge fracture as expected. Specifically, 24% (n=22) were placed into Group A (Wedge, Midshaft, 1), 36% (n=32) into Group B (Wedge, Midshaft, >1), 2% (n=2) into Group C (Wedge, Not Midshaft, 1), and 38% (n=34) were placed into Group D (no wedges).

Group D was predominantly composed of tibiae from older adults (67–102 years [n=22]) and included left (n=16) and right (n=18) tibiae from males (n=12) and females (n=22). Fifty-three fractures were classified into Group D: simple (n=29), longitudinal (n=6), and multifragmentary (n=18). Simple fractures primarily occurred in older females with shorter tibiae (mechanical span = <215 mm) (n=10). Multifragmentary fractures were more frequent in females (n=13) than males (n=5), occurred exclusively in the midshaft, and were primarily observed under lateral-medial loading (n=12) at 6 m/s (n=16).

Non-wedge fractures were most prevalent in older females (n=15) but were observed across demographics, including older males (n=7), middle-aged males and females (n=3 each), young adult females (n=4), and young adult males (n=2).

Conclusions:

Shorter tibiae from older adults were more prone to atypical fractures. While demographic and morphological variables appear to influence fracture outcomes, further research is needed to understand their complex interplay, as well as incorporate microstructural variables, which may further explain fracture variation within the same loading conditions. Controlled physical experiments provide valuable data but cannot fully explain differential outcomes, emphasizing the importance of integrating experimental and finite element computational approaches to refine injury prediction models and quantify sources of variation.