A136 Concentrated Four-Point Bending and Fracture Behavior in the Human Femora

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After attending this presentation, attendees will be aware of fracture outcomes in controlled, four-point bending tests on fresh human femora.

This presentation will impact the forensic science community by linking a known set of loading conditions with an expected range of bone behavior and fracture morphology.

Case studies and medical literature associate long bones failed in bending with butterfly fractures. It is expected these occur in a tension wedge configuration, with fracture initiating as a transverse crack at the tensile surface of a bent bone and branching toward the compressed or impact surface. Wedge configuration is forensically significant because analysts often cite the presence and orientation of butterfly fractures as diagnostic of impact direction.

Experimental research indicates this practice is problematic. Wedge fragments are not always produced in long bones failed in bending.[1-3] Furthermore, butterfly fractures may occur in a compression wedge configuration, with the transverse crack on the impact surface.[1,4]

Recently, researchers have reported on specific fracture characteristics better suited for reconstructing bending direction. Fenton et al. documented a consistent suite of incomplete fractures in dry human femora failed under three-point bending.[2] Isa et al. confirmed these features and documented consistent fracture surface features in experiments with fresh human femora.[3] These features could be used to reliably reconstruct failure in tension and compression and subsequently determine impact direction (anterior or posterior) within an experimental bending set.

Most experimental forensic research focuses on a three-point model of bending. Though compression wedges have been reported, they are observed less frequently than tension wedge-type fractures; however, Martens' engineering research team reported near-exclusive production of compression wedges in posteriorly loaded femora failed under a concentrated four-point bending configuration.[1,4] It is forensically relevant to understand if this type of bending produces a different range of fracture characteristics than three-point bending.

The objectives of the current study were: (1) to execute controlled, Martens-type four-point bending tests of fresh human femora; (2) to identify fracture outcomes, including characteristics of the complete and incomplete fractures and fracture surfaces; and, (3) to compare these fracture outcomes with those of three-point bending experiments.

Four unembalmed human femora were failed under four-point bending, with the supports at 60% bone length and the inner probes set at 10% bone length, using a servo-hydraulic testing machine. Failure was achieved via controlled displacement at a rate of 1Hz over a 20mm displacement of the inner probes, loading the posterior bone surface. All impacts were filmed with a high-speed camera at 40,000 frames per second. Following each experiment, specimens were examined for complete and incomplete fractures and fracture surface morphology.

Controlled bending tests produced compression wedge-type fractures in two specimens and distally oriented oblique fractures in two specimens. In all impacts, video footage confirmed fracture initiation on the bone's tensile side. Failure loads were 6,567N ± 1,323N. The displacement of the bone to failure was 7.99mm ± 1.80mm, and the energy input into the system until failure was 31.10J ± 15.77J.

Incomplete fracture characteristics observed in previous three-point bending impacts were not observed in long bones failed under this four-point bending configuration; however, for the two specimens with compression wedges, fracture surface characteristics were consistent with those described in previous 3-point bending impact experiments.[3] The fracture surface of the non-impact (tension) side was billowy with shallow topography. The surface of the impact (compression) side was jagged with steep topography.

The experimental results indicate there may be some differences in fracture characteristics of long bones failed under three-point and concentrated four-point bending. Regardless of the specific bending conditions, when wedge fractures are present, fracture surface characteristics are most useful for assessing failure in tension and compression and thus reconstructing impact direction.

Supporting the work of Martens et al., compression wedges and distally oriented oblique fractures were noted in this study. In all four experiments, fracture initiated on the tensile side and propagated to the compression side.

This presentation communicates the outcomes of experimentally controlled loading conditions in fresh/unembalmed human femora. The data contributed here provides a set of fracture characteristics observed in "known" cases of blunt trauma that may help experts better reconstruct the specific loading conditions in an injury scenario.

Reference(s):

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Trauma Analysis, Fracture Patterns, Biomechanics