Variability in fracture force and cross-sectional geometry between male and female tibiae in lateral impacts

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Background

Tibia fractures are the most common injury in vehicle-to-pedestrian impacts. To provide accurate injury risk predictions, sex differences in tibia properties should be investigated. The objective of this study was to identify the relationship between structural properties and cortical bone cross-sectional geometric parameters of dynamically impacted tibiae in males and females.

Methodology

Twenty-four tibiae from age-matched adult males (n=12, 24–87 years, SD ±19.1) and females (n=12, 29–86 years, SD ±18.0) were impacted in a dynamic 6 m/s lateral-medial 4-point bending scenario to replicate a vehicle-to-pedestrian blunt impact to the leg. Prior to testing, total area (Tt.Ar), cortical area (Ct.Ar), cortical thickness (Ct.Th), robustness (Tt.Ar/Length), and area moment of inertia (I) were calculated from quantitative computed tomography (QCT) scans at 50% of total tibial length. Tibia ends were potted, and strain gages were applied to mid-shaft to determine fracture timing. The testing utilized a custom-built material testing system equipped with an adjustable impactor, designed to impact the tibiae at 40% and 60% of anatomical length simultaneously. The testing fixture was equipped with two six-axis load cells beneath supported tibia ends and allowed rotation and translation of both ends.

Results and Discussion

Fracture force for the entire sample ranged from approximately 5.7–15.0 KN, females ranged from approximately 5.7–14.0 KN and males ranged from approximately 11.0–15.0 KN. Scatterplots and linear regressions were utilized to examine the relationships between fracture force and cortical bone morphometric parameters. Force was positively correlated with all of the cortical bone parameters (Tt.Ar, Ct.Ar, Ct.Th, robustness, and I). Independent-samples t-tests were used to evaluate sex differences. Males demonstrated significantly larger fracture force values than females ($p=0.03$) when impacted in an identical testing condition. Overall, males also demonstrated significantly larger values for all variables ($p<0.009$), except Ct.Th ($p=0.058$), than females at the 50% site of the tibiae (i.e., fracture location).

Cortical bone cross-sectional geometric parameters have a strong relationship with fracture force in the human tibia. This results in the trend of males exhibiting larger force magnitudes than females, as males have been shown to have larger cortical bone morphometric parameters. This highlights the importance of identifying sex-specific injury thresholds, which are provided here. There were some exceptions of females demonstrating larger cortical bone morphometric values; however, these larger values correlated with larger fracture force. This suggests that utilizing cross-sectional geometry instead of size-scaling to represent sex in finite element models would result in more accurate injury risk predictions.