INVESTIGATING THE LIKELIHOOD OF PEDIATRIC FEMUR FRACTURE DUE TO FALLS THROUGH FINITE ELEMENT ANALYSIS

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Background: When attempting to determine whether a child’s injuries are accidental or non-accidental, biomechanical evidence is needed to determine the likelihood of observed injuries being associated with the stated cause. Household falls are a commonly reported accidental injury mechanism as well as a common falsely reported cause in cases of abuse.1,2 Femur fractures can result from household falls, but in non-ambulatory children, femur fractures are more likely to be non-accidental.3 Previous testing with a modified CRABI 12-month-old anthropomorphic test device (ATD) with an improved biofidelic femur was conducted to measure femur loading in experimentally simulated falls from a bed and feet-first falls from a height. Different fall configurations included two impact surfaces (linoleum and carpet) for both fall types and two fall heights (69cm and 119cm) for the feet-first falls. A finite element (FE) model of the pediatric femur was developed and used to evaluate the potential fracture risk based on loading conditions from ATD experimental fall data. The objectives of this study are to evaluate femur stress and strain associated with common household falls and to compare these outcomes to fracture thresholds to determine fracture potential.

Methods: A 10-node tetrahedron meshed femur model was developed with Mimics v15.0.1 and 3-matic v.701 using a post-mortem diagnostic CT scan of an 11-month old femur, which was also used as the basis for the modified ATD femur. Using ANSYS v17.1, a FE femur model was developed and validated using experiments with 3D-printed glass fiber-reinforced nylon bone surrogate. Recreations of previously determined ATD loading from the simulated falls were applied to the FE model. Three ATD trials of each fall configuration (impact surface and fall height or fall dynamic, if applicable) of bed falls and feet-first falls were randomly selected for analysis. Model predicted outcomes included the maximum principal stress and strain, and von Mises stress. Table 1 contains the fracture criteria considered. ANOVA and Tukey tests were used to compare outcomes for the different fall types (α=0.05).

Results: Two different fall dynamics were observed for bed falls; either the lower (A) or upper (B) leg impacted first. There was a significant difference in maximum principal strain in bed falls between different fall dynamics (p-value = 0.028) (Figure 1). In feet first falls, there was a significant difference only between the fall heights (p-value = 0). For feet-first falls, no trials evaluated exceeded the evaluated failure criteria (Table 1). The yield strain threshold and ultimate tensile strength threshold were both exceeded in bed fall dynamics A (linoleum, n=3; carpet, n=2) and B (linoleum, n=1). Two bed fall trials exceeded the ultimate flexural strength threshold where both had a peak bending load greater than 20Nm.

Conclusion: Bed falls generated loading conditions that exceeded fracture thresholds suggesting potential for femur fracture. Feet first fall loading did not lead to stress/strain that exceeded fracture thresholds. Limitations included assessment of limited fall configurations and initial
conditions. ATD biofidelity and material property application in the model may affect femur stress/strains observed in this study.

Table 1. Fracture criteria definitions and frequency of falls that exceed each threshold. n=12 for feet first falls and bed falls.

<table>
<thead>
<tr>
<th>FE Model Predicted Outcome</th>
<th>Threshold Description</th>
<th>Threshold Value</th>
<th>Additional Criteria</th>
<th>Feet First Falls Exceeding Threshold</th>
<th>Bed Falls Exceeding Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Principal Strain</td>
<td>Yield Strain</td>
<td>0.73%</td>
<td>A minimum of 5 congruent elements must have exceeded the threshold.</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Maximum Principal Stress</td>
<td>Ultimate Flexural Strength</td>
<td>157.8MPa</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Ultimate Tensile Strength</td>
<td>100MPa</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 1. The peak maximum principal strain observed in bed falls (a) and feet first falls (b) and peak maximum principal stress observed in bed falls (c) and feet first falls (d). Error bars represent the range of values observed. In bed falls (a), fall dynamic is indicated by A or B which refers to whether the lower or upper leg impacted first, respectively, in the ATD experiment. n=3 for bed falls and n=3 for feet first falls.
References


