Development of In Silico Pediatric Femur Model to Evaluate Femur Loading in Bed Falls

Keyonna Mckinsey[1], Gina Bertocci[1], Angela Thompson[2]
1- Department of Bioengineering, University of Louisville, Louisville KY
2 - Department of Engineering Fundamentals, University of Louisville

Background

- Household falls are a common accidental injury mechanism as well as a common falsely reported cause in cases of abuse.
- In non-ambulatory children, femur fractures are more likely to be due to abuse.
- Clinicians must be able to delineate between abuse and accidental injuries.
- Currently little biomechanical evidence to distinguish accidental and non-accidental injuries.

- Previously, 12-month-old anthropomorphic test dummy (ATD) with a biofidelic femur was instrumented with two triaxial load cells and strain gauge to measure femoral loading
- ATD was used in simulations of bed falls onto two impact surfaces (linoleum and padded carpet) from a height of 61cm.
- The biofidelic femur was based upon a representative infant CT images.

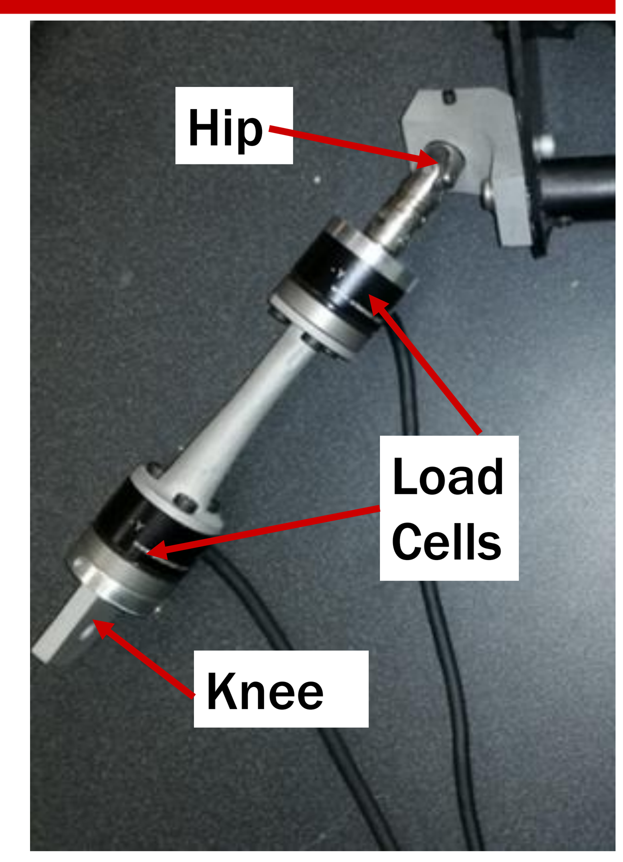

Figure 1. ATD Femur Assembly

Objective

- Develop an *in-silico* femur model
- Evaluate stress and strain distribution in the femur during a bed fall
- Evaluate different material applications to the *in-silico* model and their effect on outcomes

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Methods

- A post-mortem diagnostic CT scan of 11-month old was used to derive a 10-node tetrahedron femur model (ANSYS) meshed in 3-matic (Materialise, Ann Arbor MI). (341736 elements)
- Used phantom-less calibration to define relationship between HU and bone mineral density
- Analyzed in ANSYS Workbench (ANSYS Inc., USA) (Figure 2) using applied femur loads and constraints similar to those in bed fall experiments. Simulation of falls for each impact surface were evaluated.
  - Peak values of the applied forces and moments can be found in Table 1.
  - ATD strain gauge outputs were used to compare two distal femur constraint scenarios (Figure 2b and 2c) using the linoleum loading conditions.
- Evaluated 3 different material application approaches in the model using Mimics (Materialise, Ann Arbor MI).
  - 10 and 50 bins, equally distributed across span of HU values
  - 2 bins: Median HU of the cortical and trabecular segments applied to their respective regions

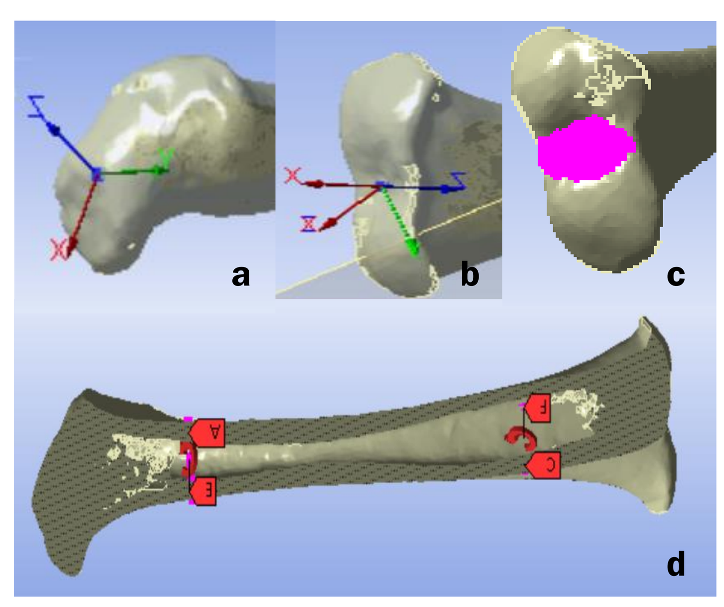


Figure 2. Applied constraints and loads in ANSYS Workbench.

- **(a) Universal joint at the proximal end, no rotation about the longitudinal axis.**
- **(b) Fixed joint at the distal end**
- **(c) Fixed displacement of the intercondylar (distal) region in pink**
- **(d) Locations of force application.**

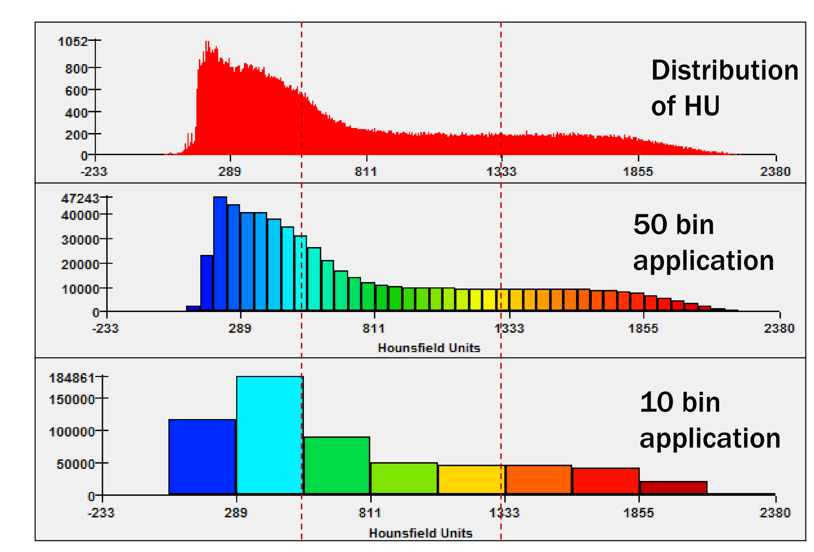


Figure 3. Distribution of bins for the different material applications. The dotted lines represent the median values used for the 2-bin application

Table 1. Peak Forces and Moments Applied to Model

Impact Surface	Tension (N)	Shear (N)	Bending (Nm)	Torsion (Nm)
Carpet	117	245	23	1.57
Linoleum	125	154	20	1.88

Results

- Fixed intercondylar region constraint setup had a better agreement with the ATD's strain gauge output.
  - This setup was used in the evaluation of biomechanical outcomes of the bed falls
- Linoleum and carpet surface resulted in similar outcome values
- The maximum principal strain occurred at the proximal lateral end for both surfaces
- 50 bin and 10 bin application resulted in similar outcomes
- The maximum principal strain in the 2 bin application was consistently lower
- Limitations: Only considered stress and strain values of the femur shaft to be consistent with ATD load cells.

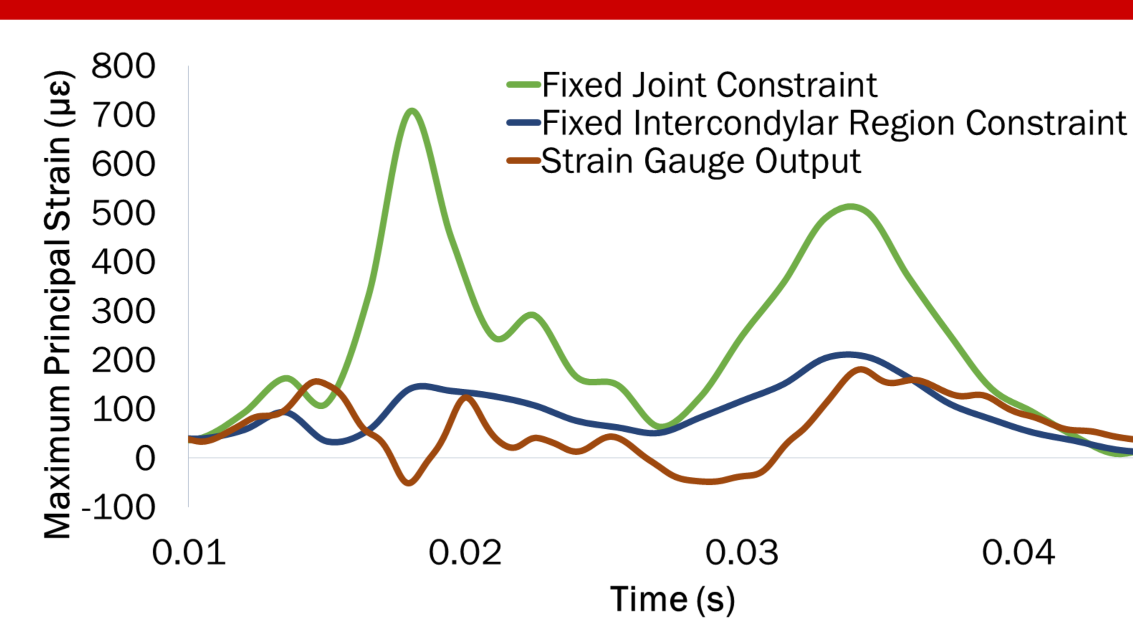


Figure 4. ATD experiment vs model

Table 2. Maximum Femur Shaft Outcome Measures

Impact Surface	Carpet		Linoleum	
Material Application	Maximum Principal Stress (MPa)	Maximum Principal Strain (ε)	Maximum Principal Stress (MPa)	Maximum Principal Strain (ε)
50 bin	1422	0.084	1256	0.074
10 bin	1461	0.083	1290	0.073
2 bin	1132	0.051	1003	0.045

Figure 5. Maximum principal strain of femur shaft cross section. Linoleum loading conditions. Anterior View. Lateral to medial: left to right

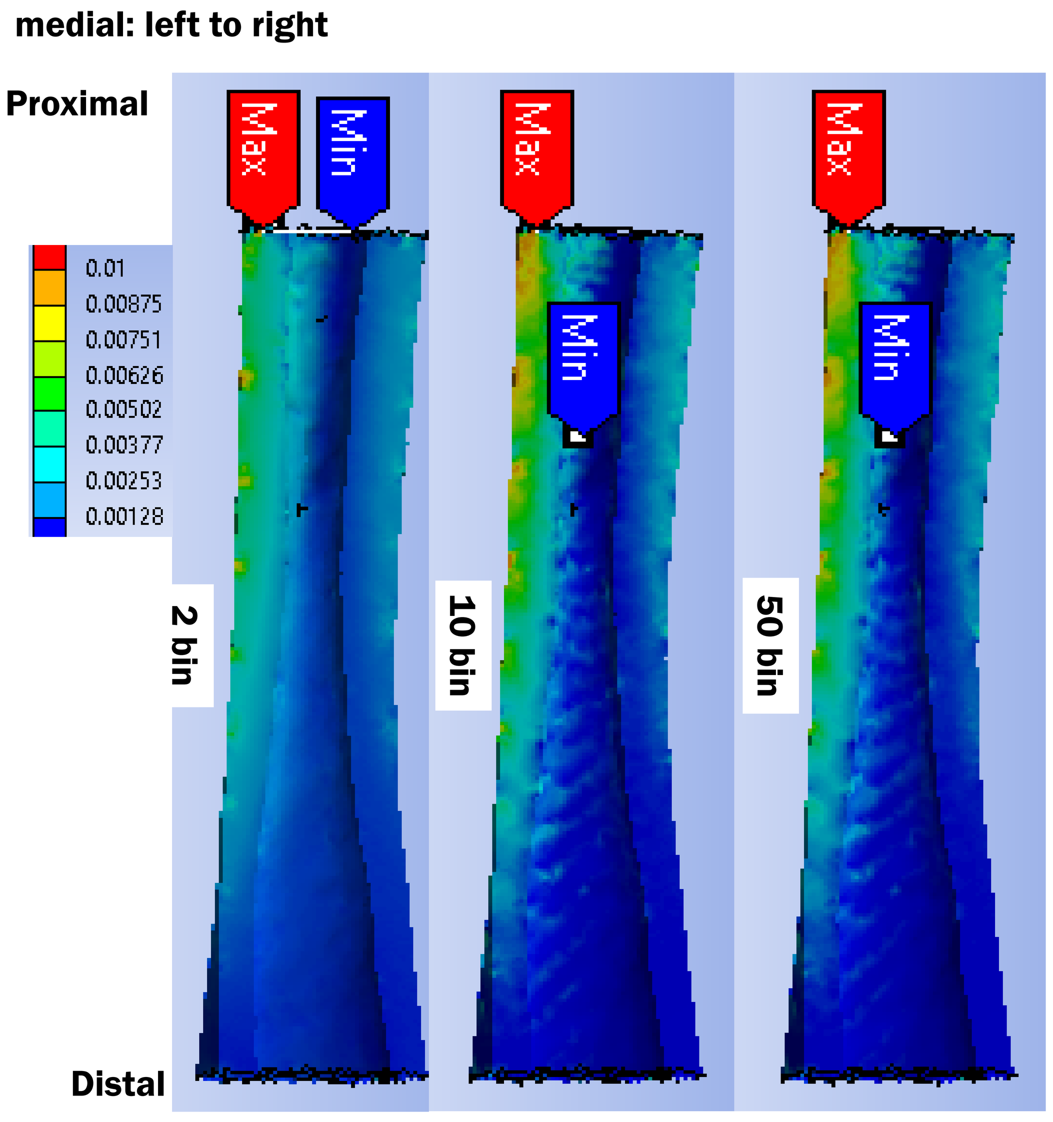
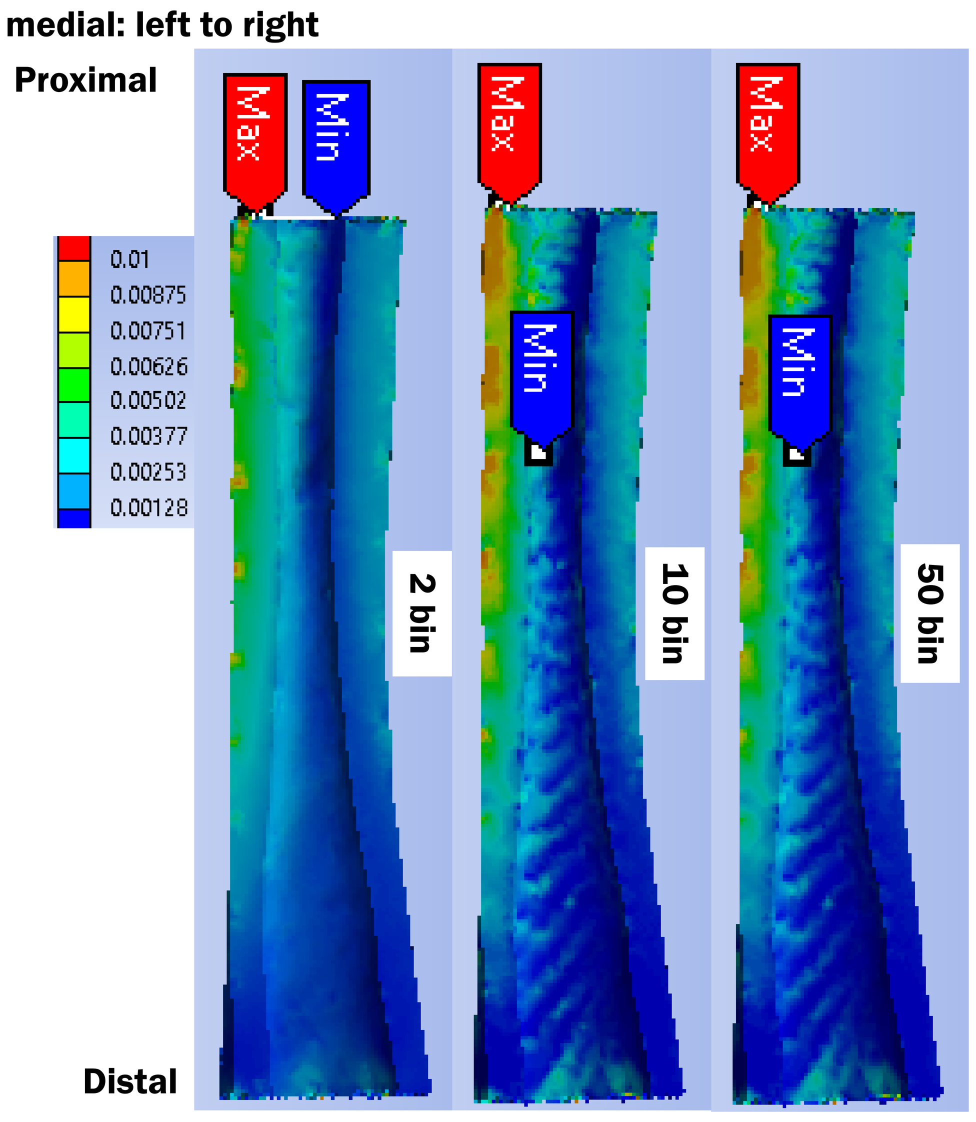


Figure 6. Maximum principal strain of femur shaft cross section. Carpet loading conditions. Anterior View. Lateral to medial: left to right



Conclusions

- Both conditions resulted in similar outcomes suggesting similar risks of fracture.
- The 10 bin model would be adequate to evaluate future loads since it is similar to the 50 bin.
  - Reduced number of bins is preferable
- Future work:
  - Application of remaining ATD femur loads
  - Further mechanical validation of the model