DEVELOPMENT OF AN OLDER OCCUPANT FE MODEL INCORPORATING GEOMETRY, MATERIAL PROPERTIES, AND CORTICAL THICKNESS VARIATION

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Motivation

- Elderly population is growing
- Increased fragility and frailty

Elderly population growth:
- 2010:
  - <65: 87%
  - 65+: 13%
- 2040:
  - <65: 80%
  - 65+: 20%

Graph showing:
- Injury tolerance decreases with age
- Mortality, morbidity, complications increase with age
Global Human Body Models Consortium

- Develop & maintain high biofidelic FE human body models for crash simulation
- Representative of a 50\textsuperscript{th} percentile male (M50)
- Based on medical images of a 26 YO & literature data
Objective: Develop an older occupant GHBMC model representing a 65 year old 50th percentile male.
Overview of 65 YO Model

Geometry (Shape) Changes

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Overview of 65 YO Model

Material Property Changes

Golman 2014; Kemper 2005; Kemper 2007; Dokko 2009; El-Jawahri 2010
Overview of 65 YO Model

Cortical Thickness Changes
Research Plan

Scan and landmark collection

Shape variation functions

Model morphing

FE analysis & parametric simulation

CT and MRI Scans

Model Parameters
Shape landmark data
Material properties
Cortical thickness
Scan Collection

- 343 Thoracic CTs, 120 MRIs, 120 Head CTs
- Demographic data: sex, age, weight, height, BMI

<table>
<thead>
<tr>
<th>Pediatric</th>
<th>Adult</th>
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<tbody>
<tr>
<td>0-3 mo.</td>
<td>20-30 yr</td>
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<tr>
<td>3-6 mo.</td>
<td>30-40 yr</td>
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<tr>
<td>6-9 mo</td>
<td>40-50 yr</td>
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<tr>
<td>9-12 mo</td>
<td>50-60 yr</td>
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<tr>
<td>1-3 yr</td>
<td>60-70 yr</td>
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<td>3-6 yr</td>
<td>70-80 yr</td>
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<td>6-10 yr</td>
<td>80-90 yr</td>
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<tr>
<td>10-20 yr</td>
<td>90-100 yr</td>
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</tbody>
</table>
Segmentation Methods

**Soft Tissue**

- Fully automated brain label segmentation

**Bone**

1. Bone Threshold
2. Region grow
3. Manual edit
4. Hole filling
Homologous Landmark Collection
Registration of Atlas Landmarks to Subject Segmentations
Geometric Morphometrics

1. Initial Location
   *Points in image space*

2. Translation
   *Align centroids*

3. Rotation
   *Rotation about centroid*

4. Scaling (Size)
   *Dilatation or compression*

*Homologous Landmarks*

*Generalized Procrustes Analysis (GPA)*

*Shape Functions*
Lateral Ventricle Shape Changes (Males) – Urban et al. (Biomed Sci Instru 2012)
Rib Cage Shape Changes (Males) - Weaver et al. (J Anatomy 2014), Weaver et al. (J Morphology 2014)
UMTRI Mesh Morphing

**Femur**

- Template Mesh with Landmarks and Patient Geometry
  - Landmarks
- Mesh Morphed to Patient Geometry with Landmarks
- Black: Surface Mesh
  - Blue: Morphed Mesh
  - Red: Projected Mesh

**External Anthropometry**

- GHBMC

*UMTRI M50 Body Shape*

(Future: implement age effect)
"Thin-plate spline" refers to a physical analogy involving the bending of a thin sheet of metal.
Thin-Plate Spline Interpolation Model Morphing

Homologous LMs
GHBMС vs 65yr Male

Control Points

GHBMС M50 v4.2

65yr Male Morphed GHBMС
Preliminary Morphing Results

GHBMC
65yr Male
65YO Material Properties

• Adapted from literature
• Ultimate strain of the ribs and ultimate stress of the femur cortical bone decreases significantly with age

Ribs

Femur

Golman 2014; Kemper 2005; Kemper 2007; Dokko 2009; El-Jawahri 2010
Cortical Thickness Estimation
Treece et al. 2010, 2012

1. Computes HU value (density) from entire CT scan that best represents cortex
2. Algorithm uses density value to estimate cortical thickness over entire surface

Outputs point cloud with associated cortical thickness values at each point
Rib Cortical Thickness Variation with Age

Rib: 5, Ring: 5, Angle: 266
Rib Cortical Thickness Comparison

GHBMG

65yr Male
Skull Cortical Thickness Variation

Lillie et al. (J Anatomy 2015)
Skull Cortical Thickness Comparison

GHBMC

65yr Male
Femur Cortical Thickness Comparison

GHBMC

65yr Male
Ongoing Work

- Characterize 65YO pelvis, tibia, & external anthropometry variation
- Morph full body
- Implement 65YO material properties & cortical thicknesses
- Simulation & validation
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Summary & Conclusions

• 65 YO GHBMC model development
  – Shape variation in brain, skull, thorax, lower extremities, and external anthropometry
  – Bone material property variation
  – Cortical thickness variation (skull, ribs, lower extremity)

• Investigating age-specific injury mechanisms
Thank you!

NHTSA
www.nhtsa.gov

OASIS Project for MRI scans
P50 AG05681, P01 AG03991, R01 AG021910,
P20 MH071616, U24 RR021382

Center for Injury Biomechanics

Wake Forest School of Medicine

Virginia Tech

COLLEGE of ENGINEERING