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

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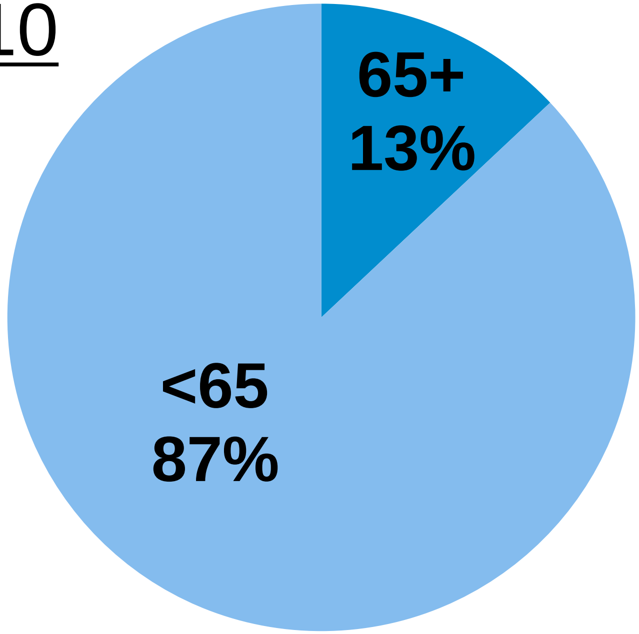
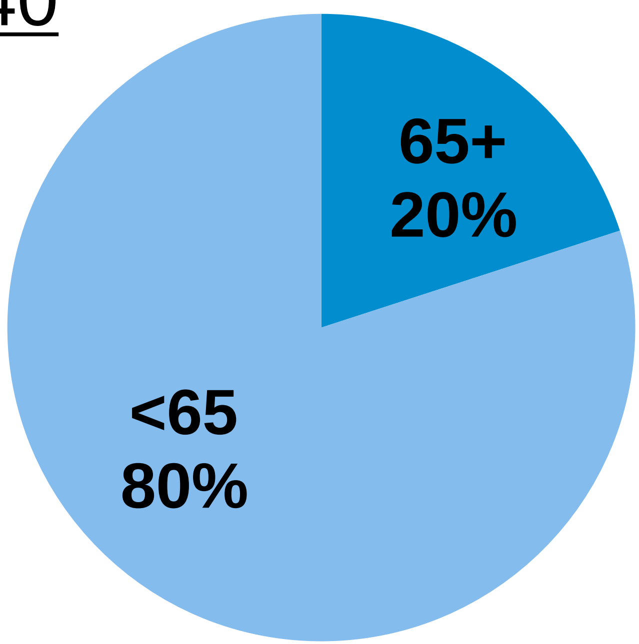
UMTRI

Motivation

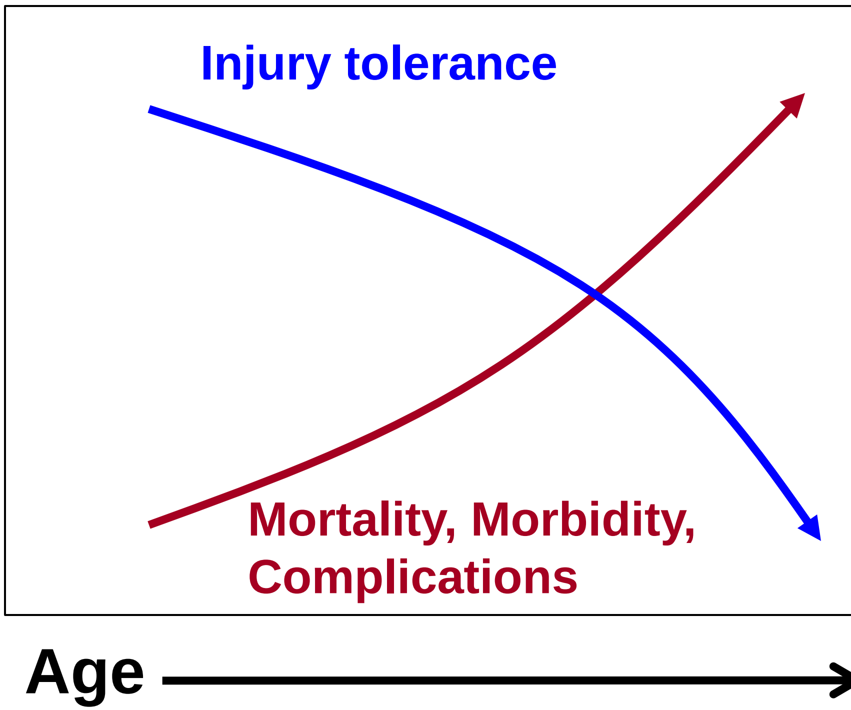
2010



2040

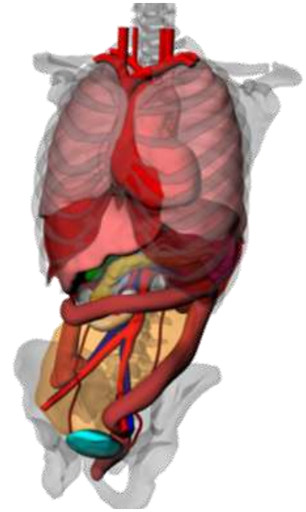


- Elderly population is growing
- Increased fragility and frailty



Global Human Body Models Consortium

- Develop & maintain high biofidelic FE human body models for crash simulation
- Representative of a 50^{th} percentile male (M50)
- Based on medical images of a 26 YO & literature data



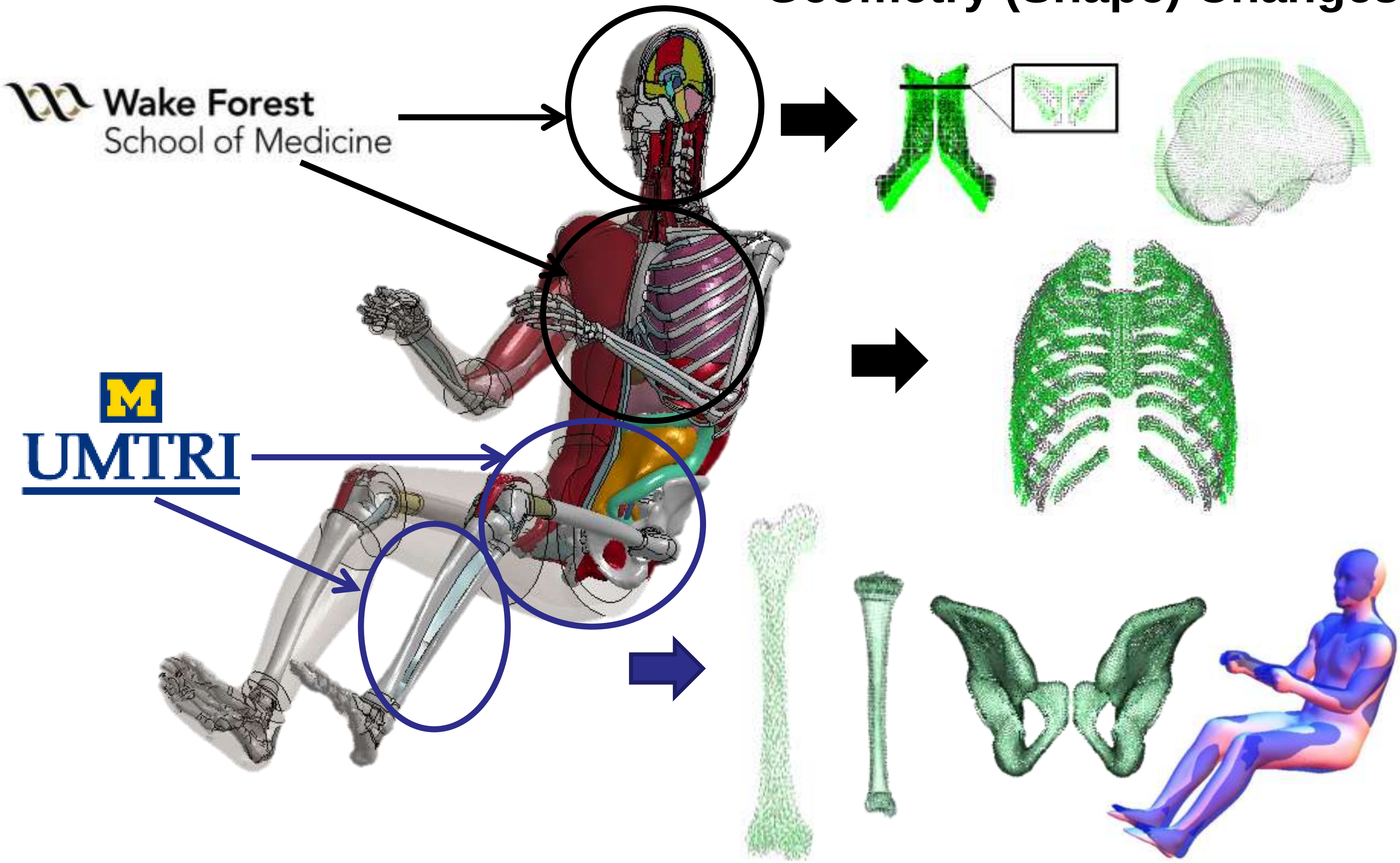
Wayne State University
University of Waterloo
University of Virginia
IFSTTAR
VirginiaTech
UAB
Wake Forest School of Medicine

Objective: Develop an older occupant GHBMC model representing a 65 year old 50th percentile male

Characterize Shape, Material Property, Cortical Thickness → **Model Morphing** → **Simulation** → **Understand age-specific injury mechanisms**

Overview of 65 YO Model

Geometry (Shape) Changes



Overview of 65 YO Model

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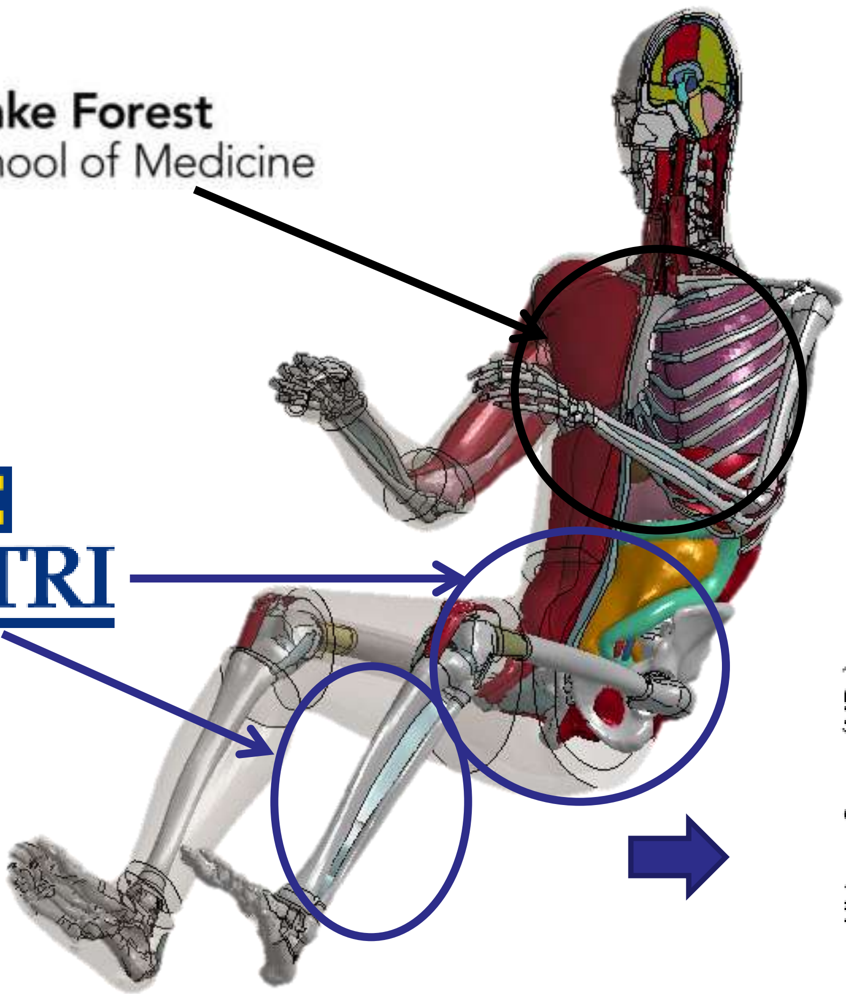
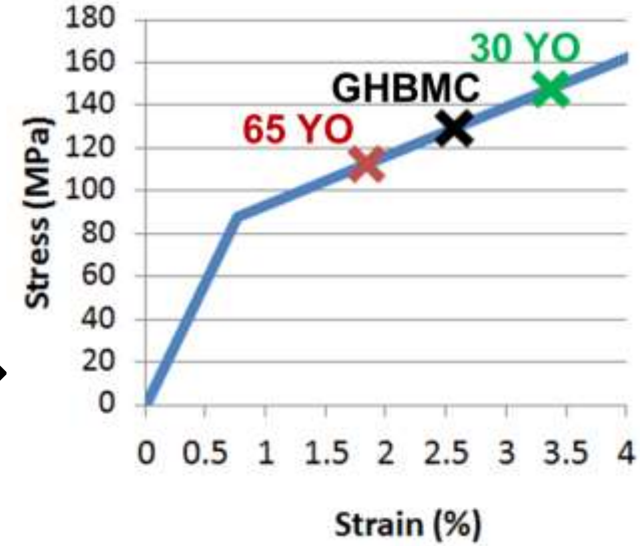
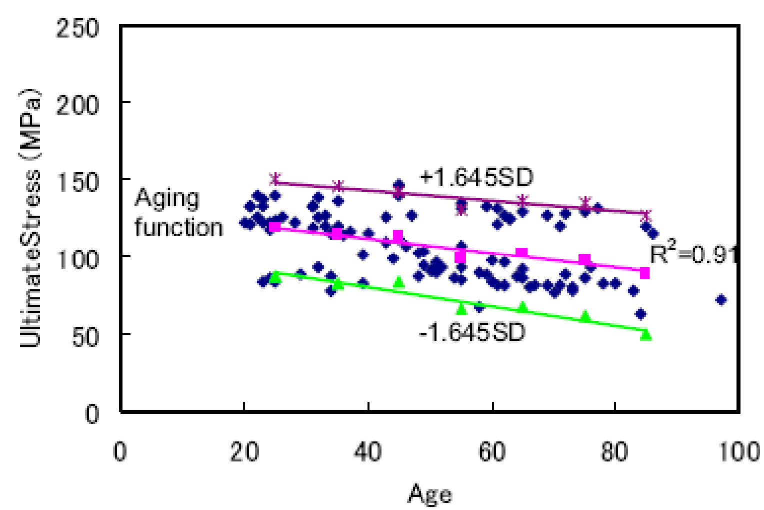


Material Property Changes





Golman 2014; Kemper 2005; Kemper 2007; Dokko 2009; El-Jawahri 2010

Overview of 65 YO Model

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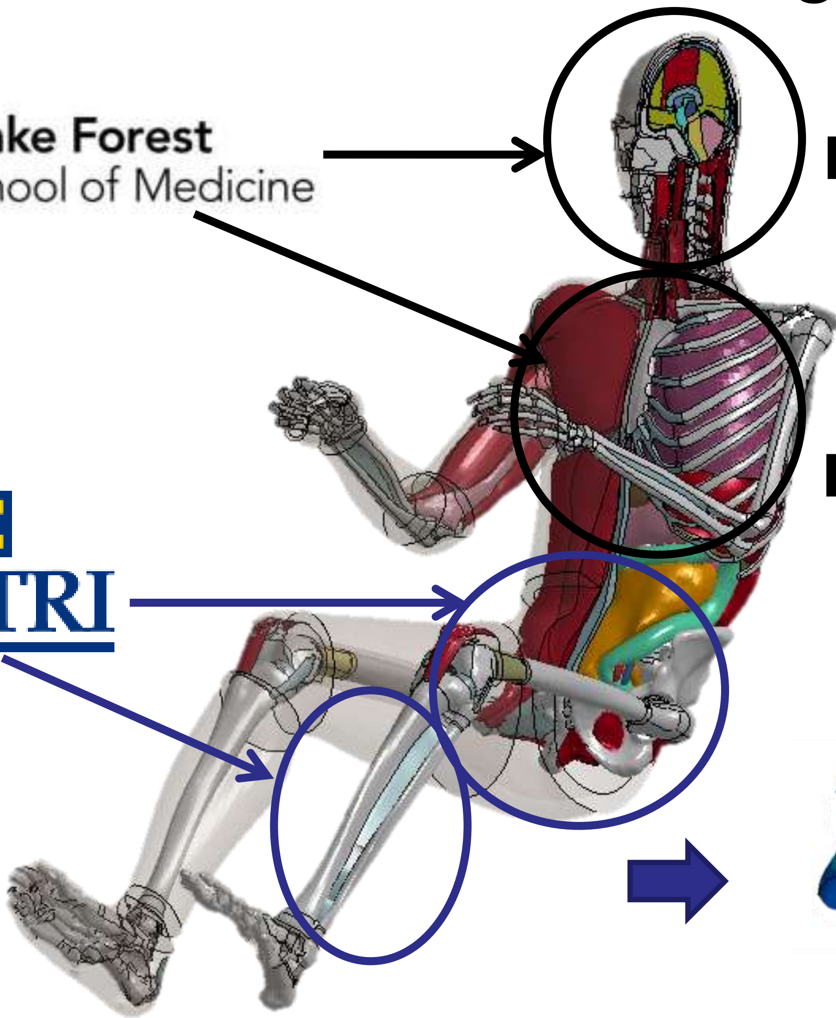
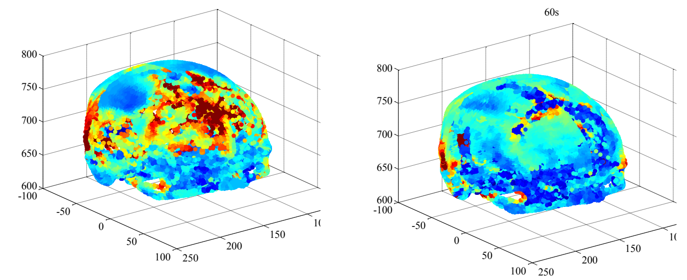
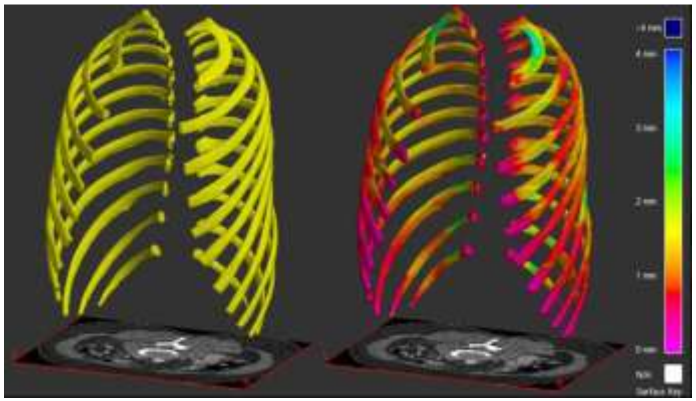
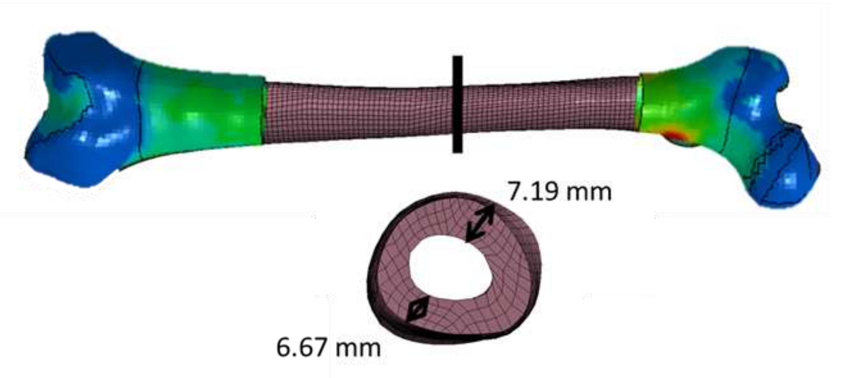


Cortical Thickness Changes







Research Plan

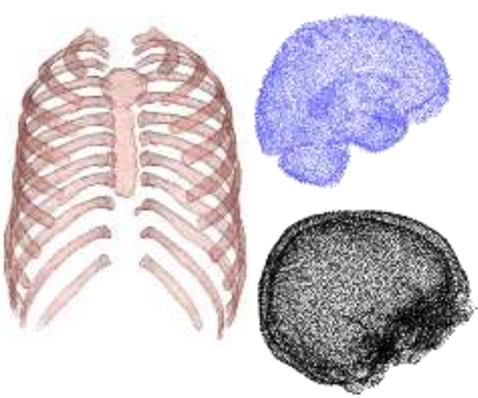
Scan and landmark collection

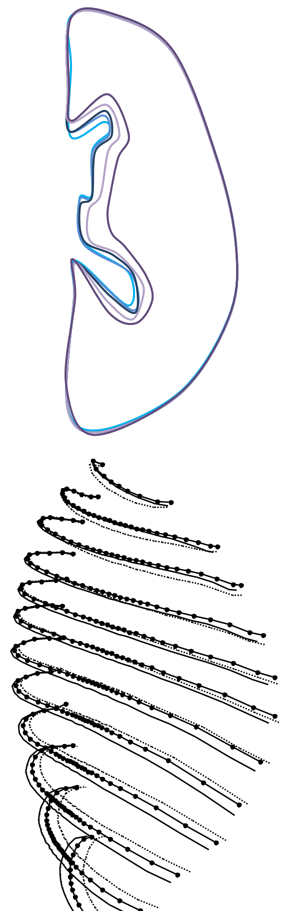
Shape variation functions

Model morphing

FE analysis & parametric simulation

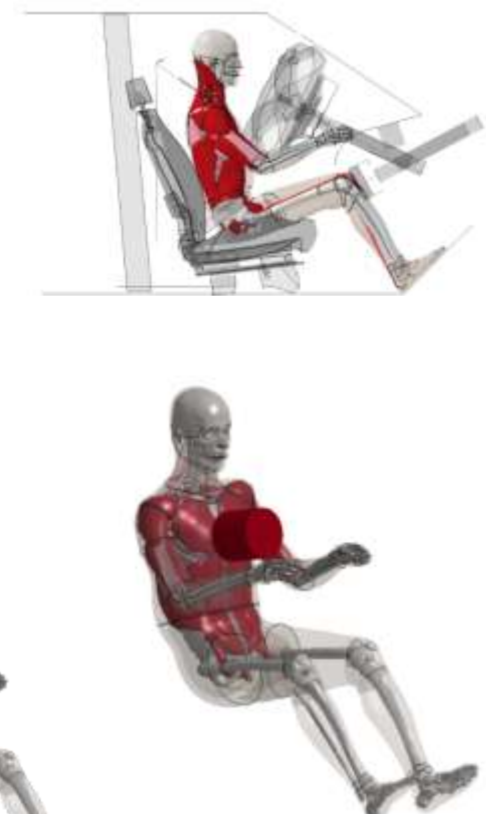
CT and MRI Scans





Model Parameters

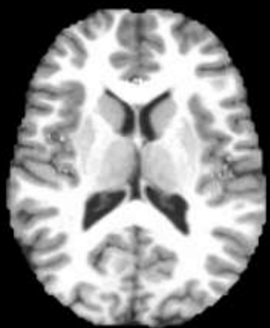
Shape landmark data
Material properties
Cortical thickness



Scan Collection

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

Normal MRI Scan



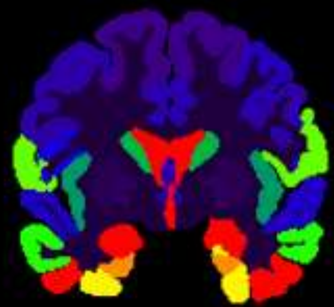
Normal Thoracic CT Scan

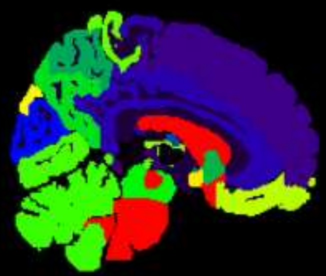
Rib cage only → Pediatric; Rib cage and head → Adult

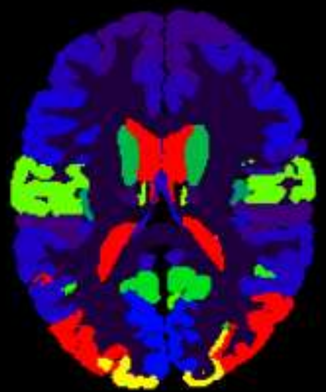
Pediatric	Adult
0-3 mo.	20-30 yr
3-6 mo.	30-40 yr
6-9 mo	40-50 yr
9-12 mo	50-60 yr
1-3 yr	60-70 yr
3-6 yr	70-80 yr
6-10 yr	80-90 yr
10-20 yr	90-100 yr

Segmentation Methods

ICBM Labels

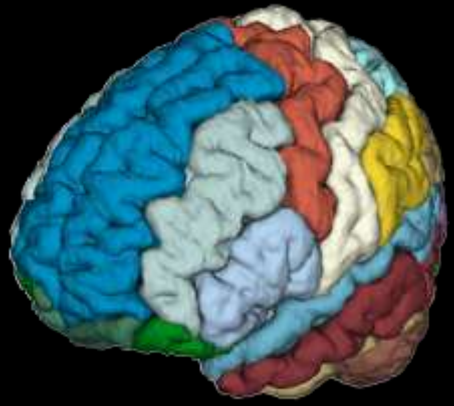






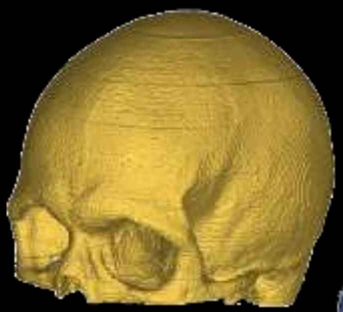
Soft Tissue

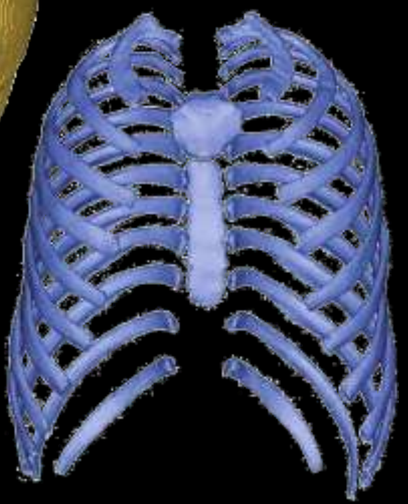
Fully – automated brain label segmentation



Bone

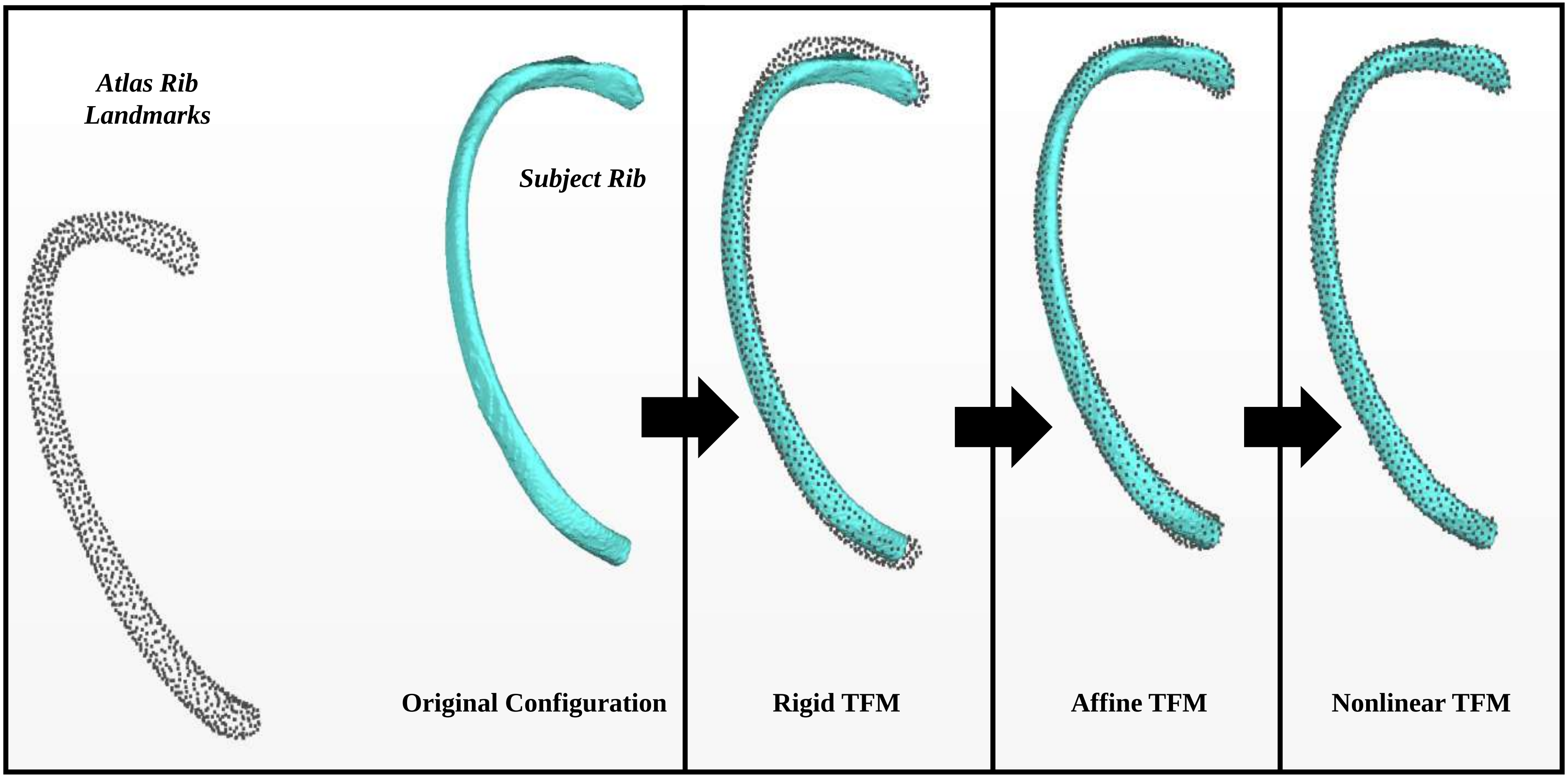
1. Bone Threshold
2. Region grow
3. Manual edit
4. Hole filling





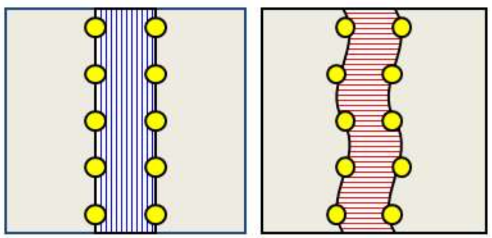
Homologous Landmark Collection

Registration of Atlas Landmarks to Subject Segmentations



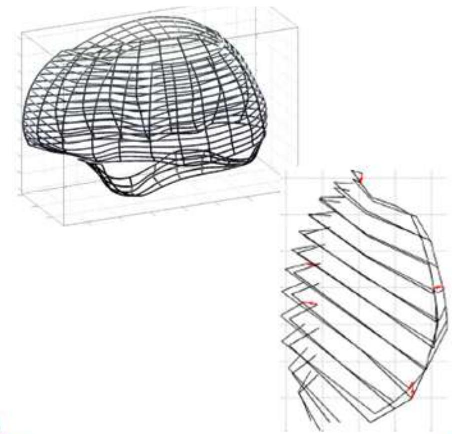
Geometric Morphometrics

Homologous Landmarks



Generalized Procrustes Analysis (GPA)

Shape Functions



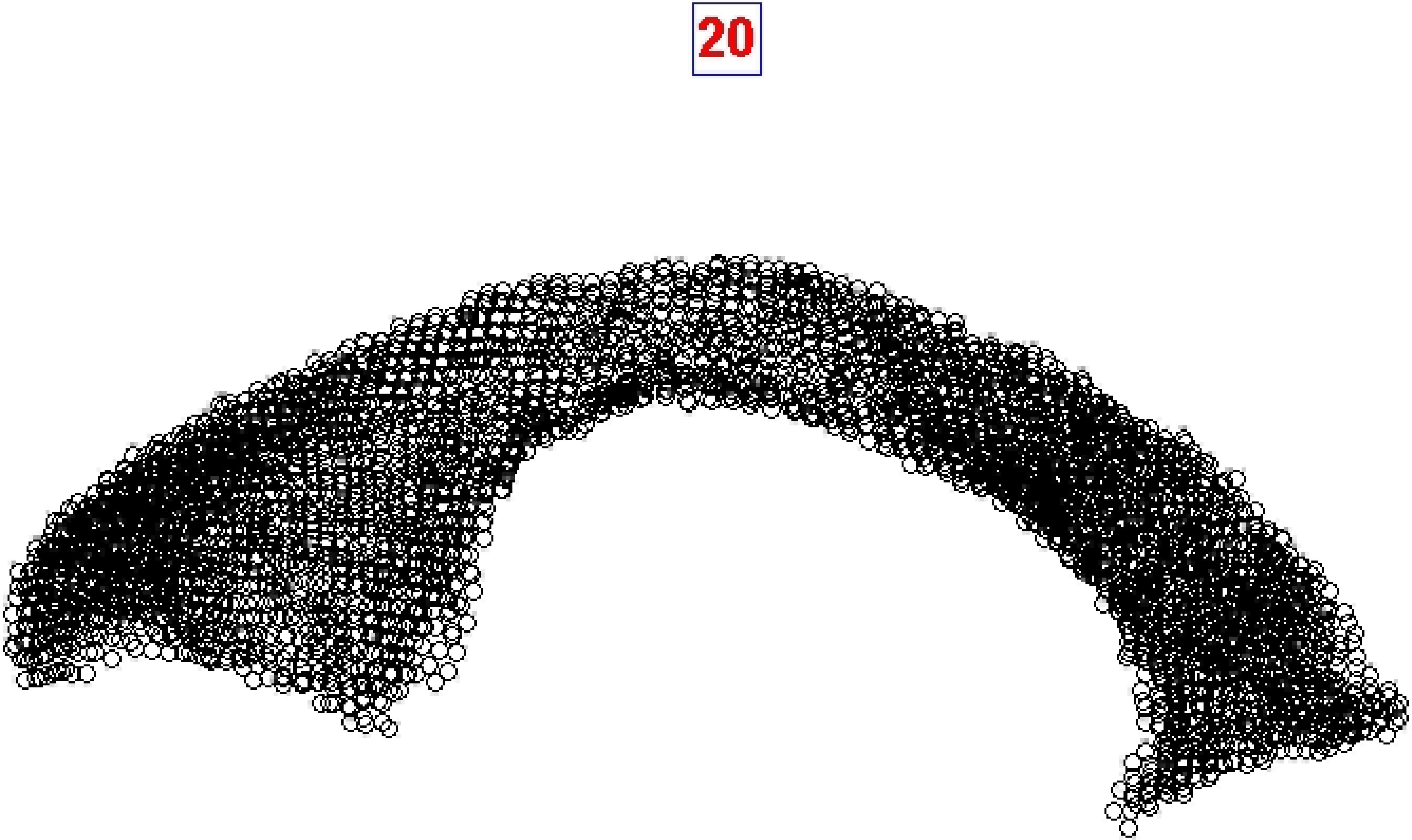
1. Initial Location
Points in image space

2. Translation
Align centroids

3. Rotation
Rotation about centroid

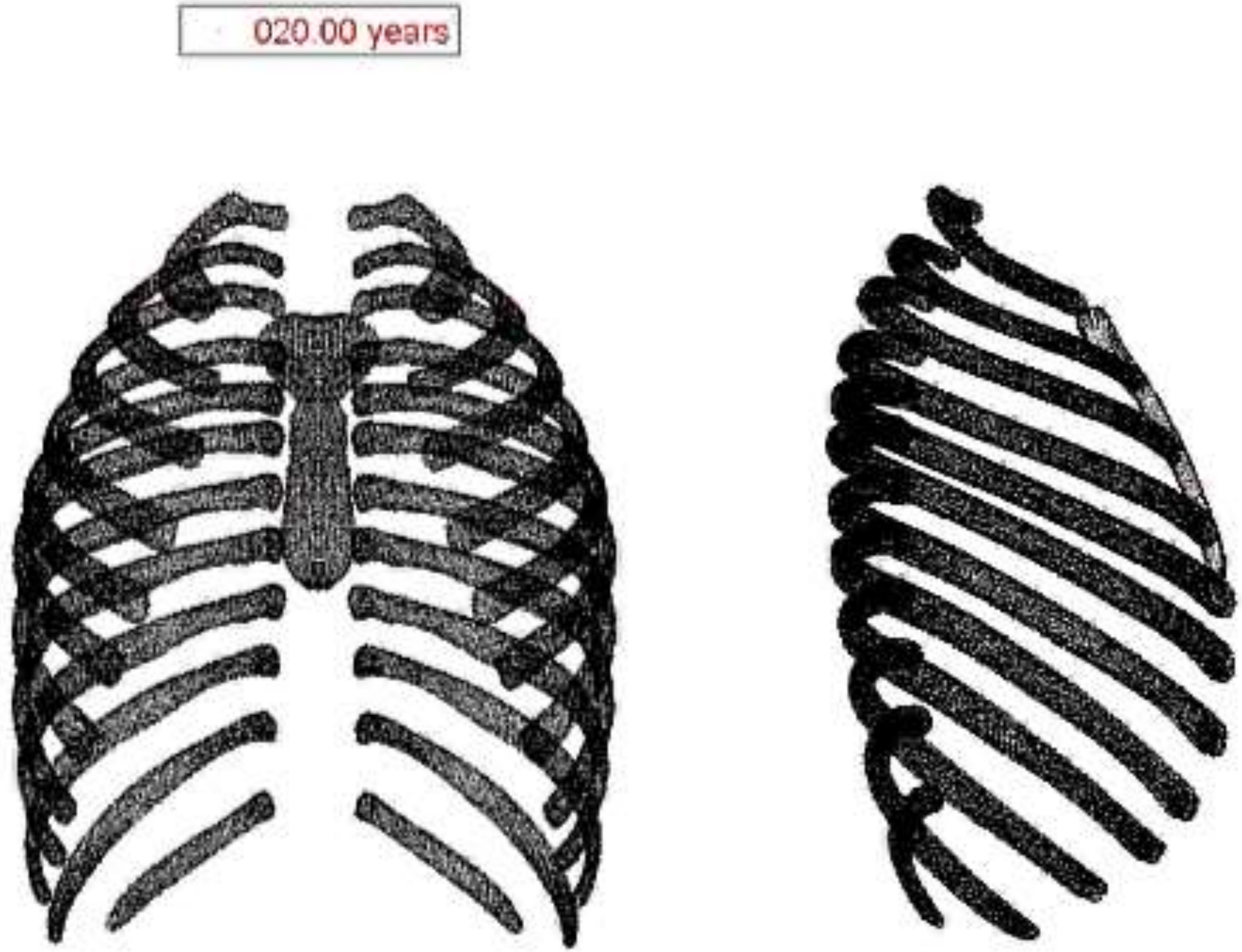
4. Scaling (Size)
Dilatation or compression

Lateral Ventricle Shape Changes (Males) –
Urban et al. (Biomed Sci Instru 2012)



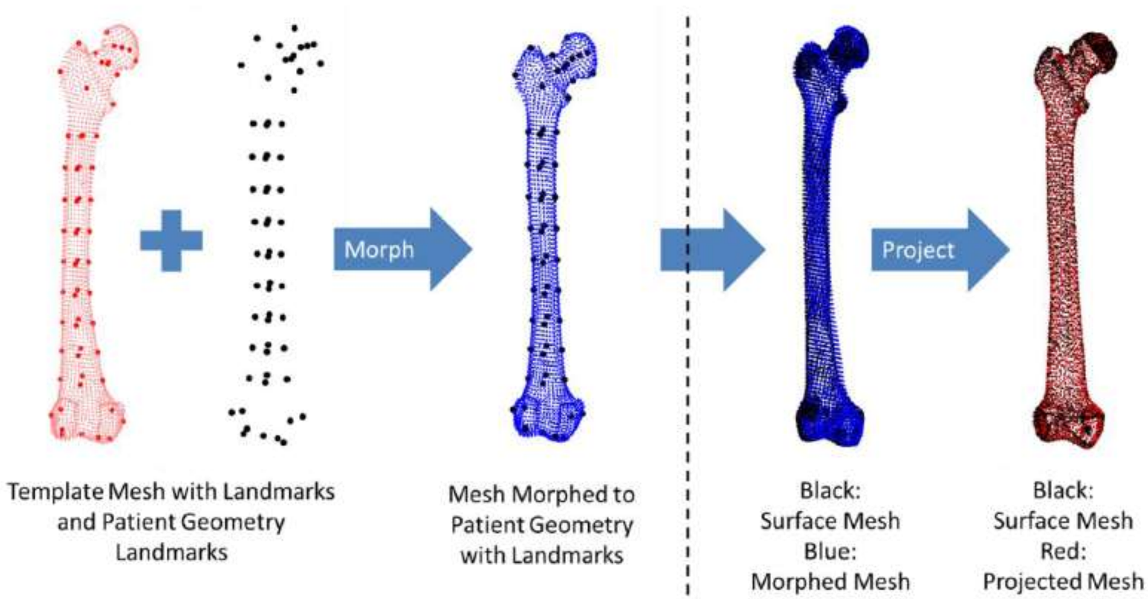
Rib Cage Shape Changes (Males) -

Weaver et al. (J Anatomy 2014), Weaver et al. (J Morphology 2014)

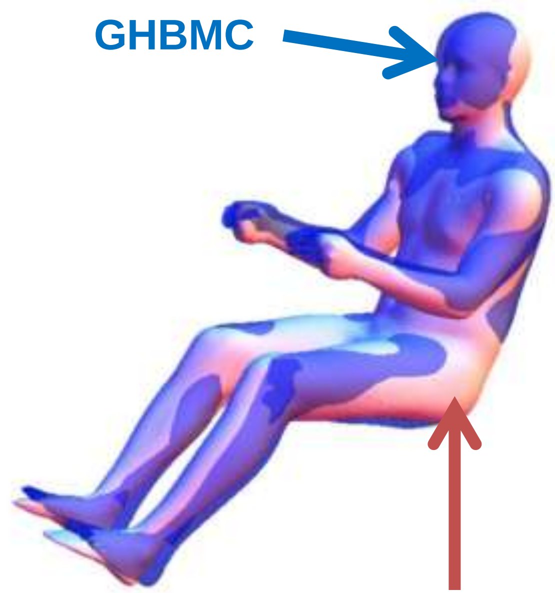


UMTRI Mesh Morphing

Femur



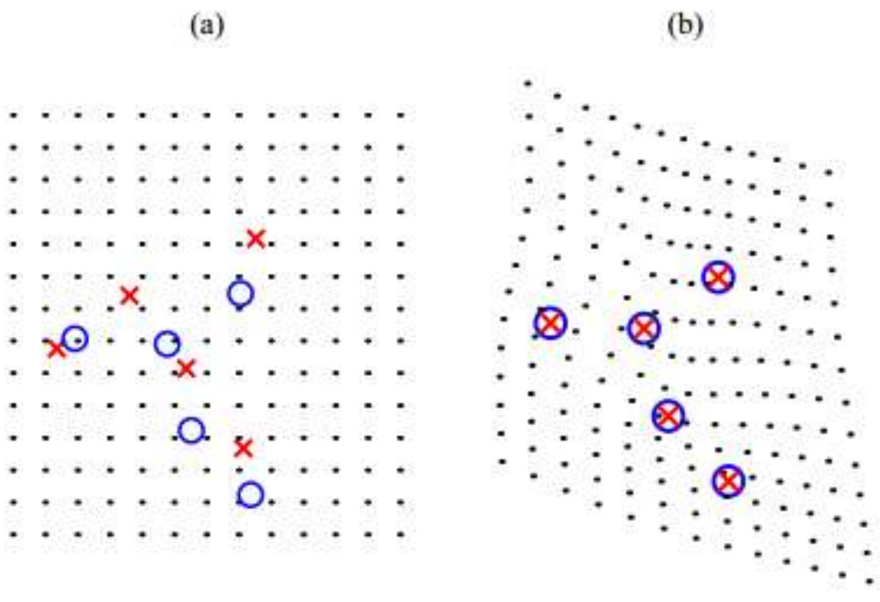
External Anthropometry

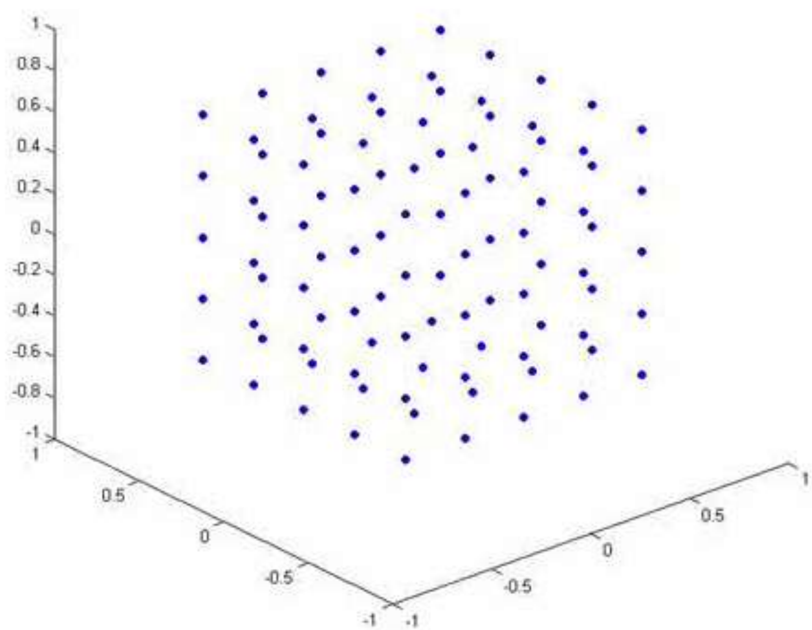


UMTRI M50 Body Shape
(Future: implement age effect)

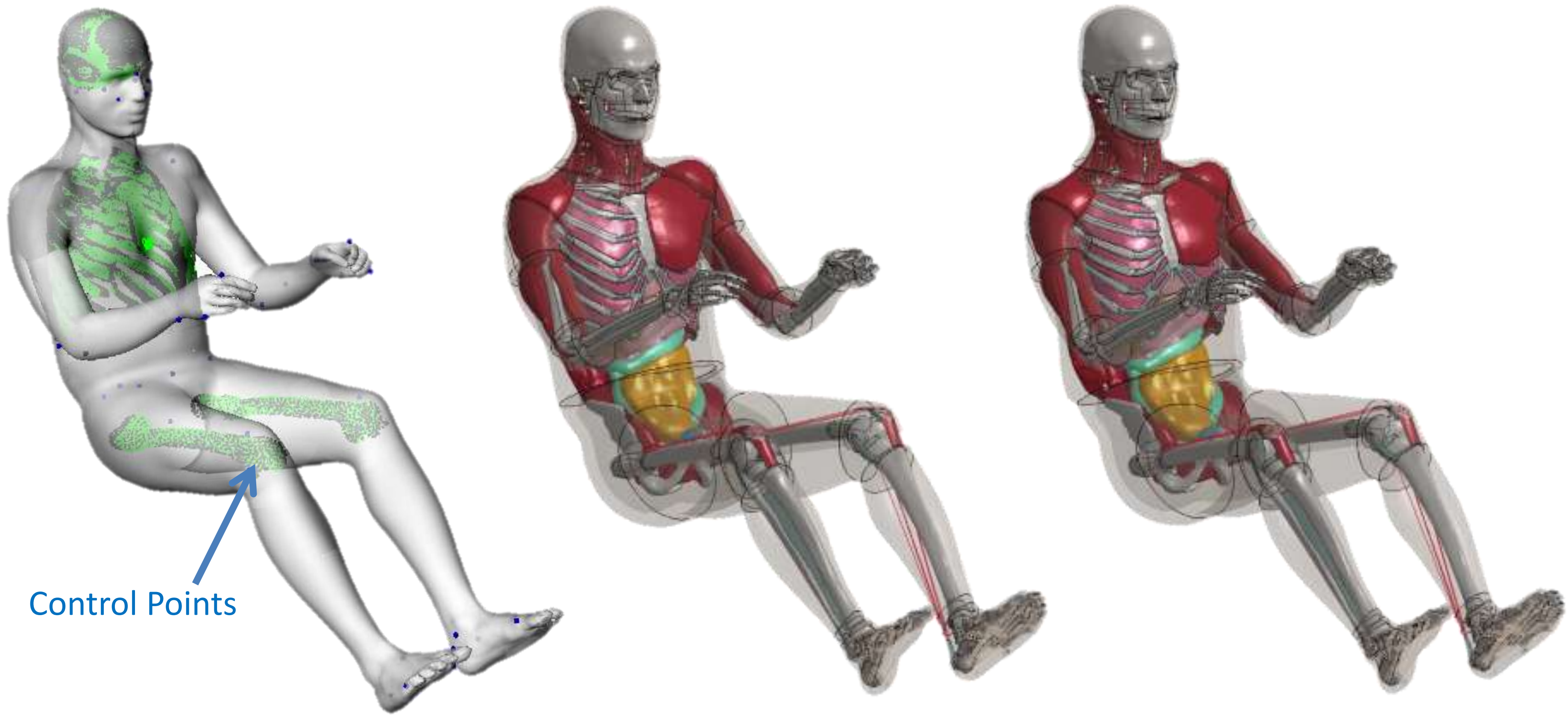
Thin-Plate Spline Interpolation Model Morphing

"Thin-plate spline" refers to a physical analogy involving the bending of a thin sheet of metal





Thin-Plate Spline Interpolation Model Morphing



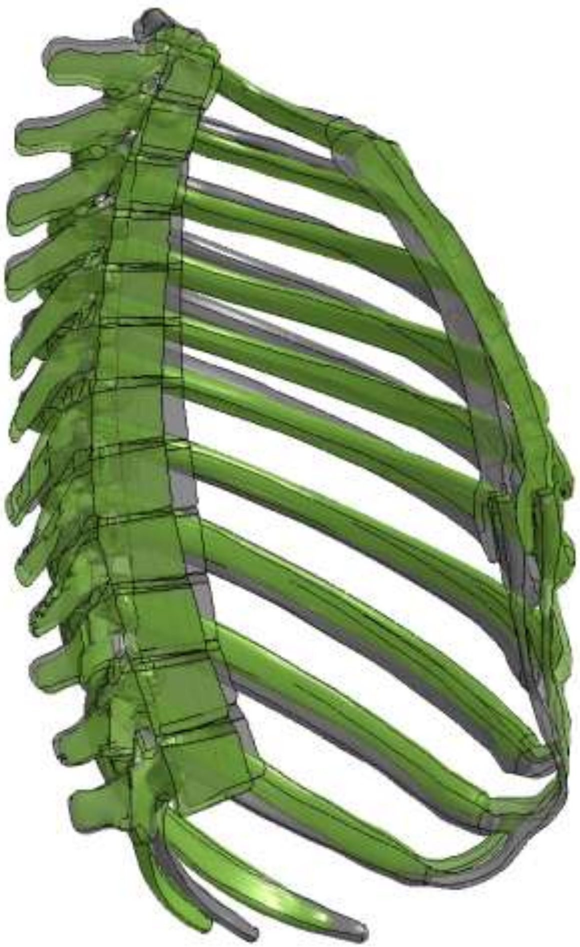
Homologous LMs GHBMC vs 65yr Male

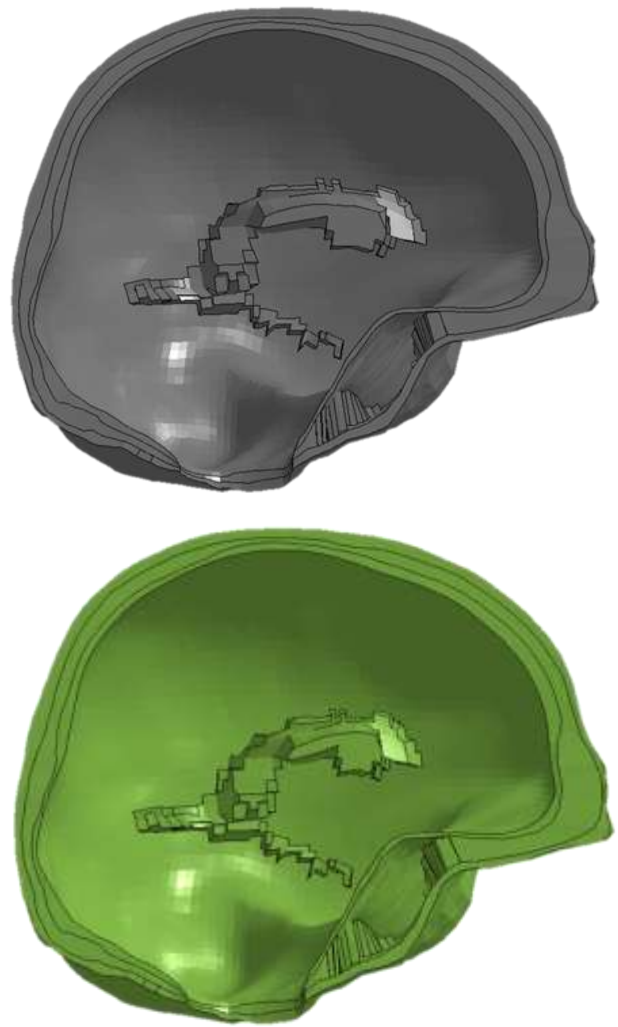
GHBMC M50 v4.2

65yr Male Morphed GHBMC

Preliminary Morphing Results

GHBMC
65yr Male

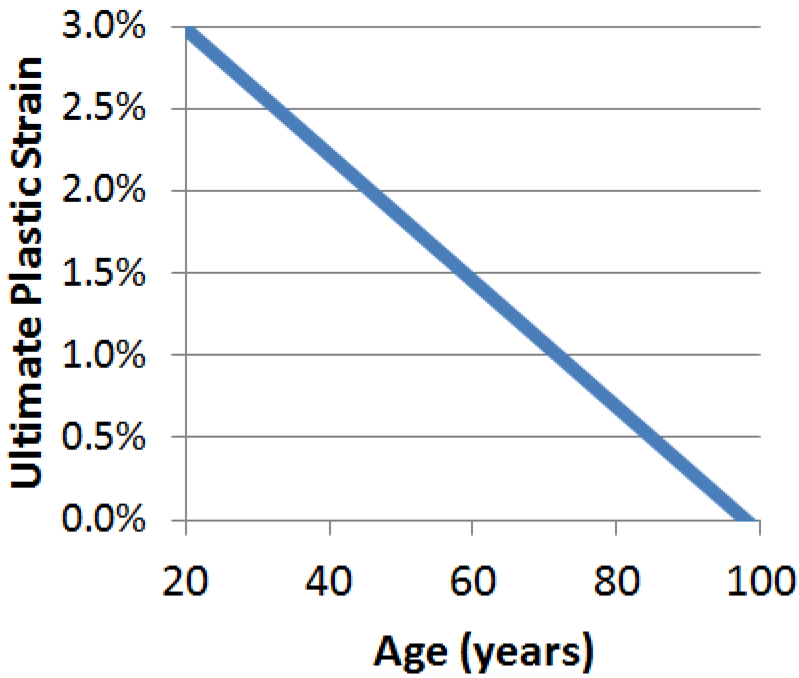




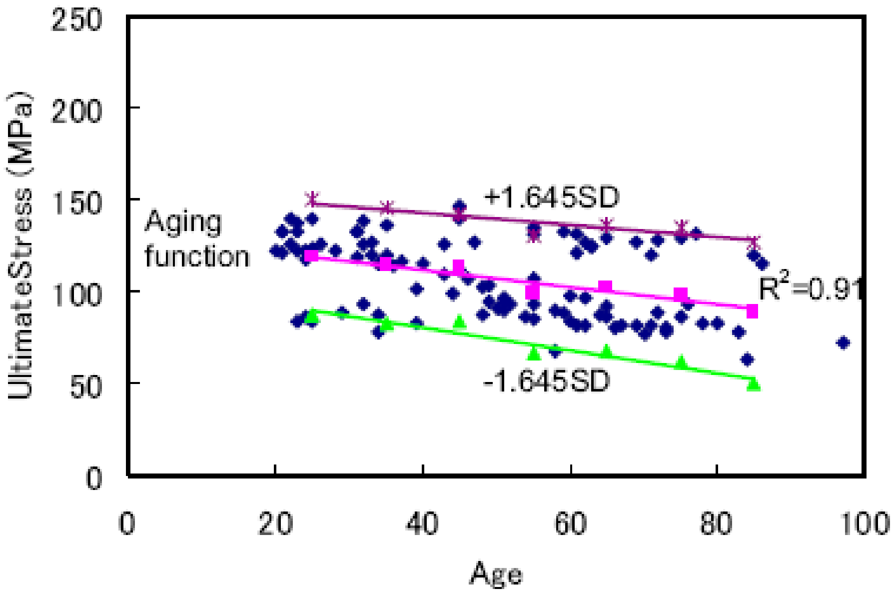
65YO Material Properties

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

Ribs



Femur

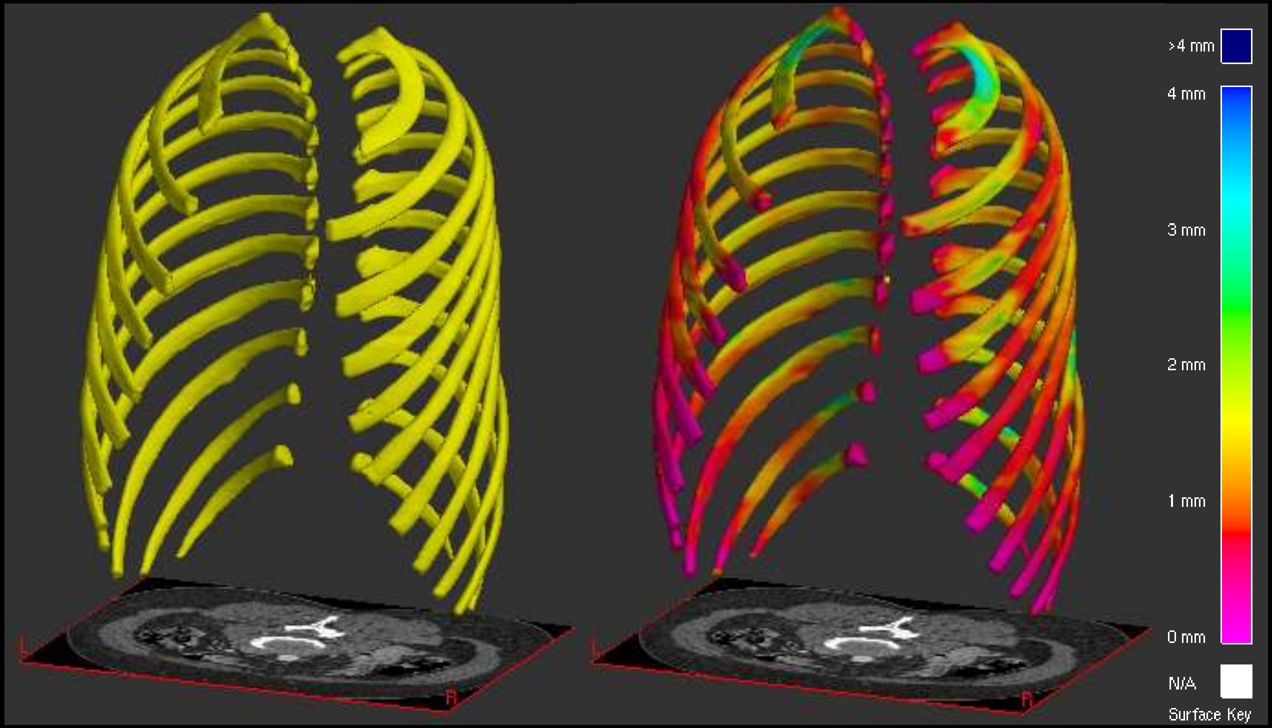


Golman 2014; Kemper 2005; Kemper 2007; Dokko 2009; El-Jawahri 2010

Cortical Thickness Estimation

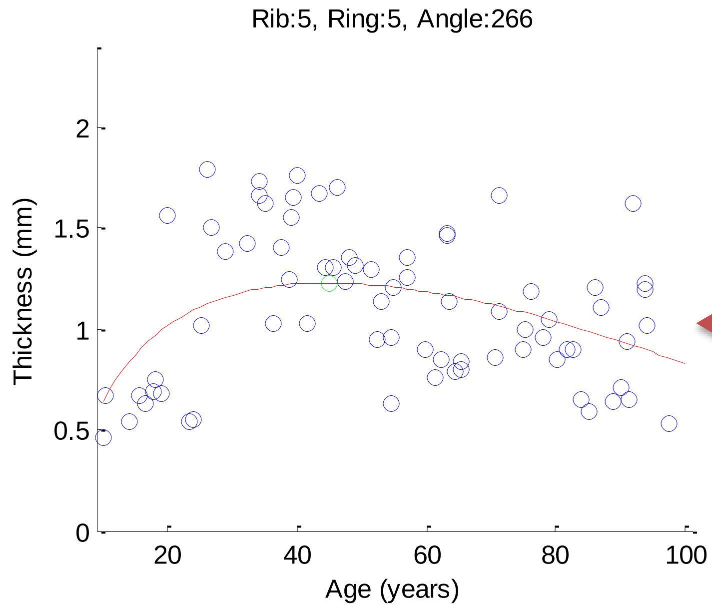
Treece et al. 2010, 2012

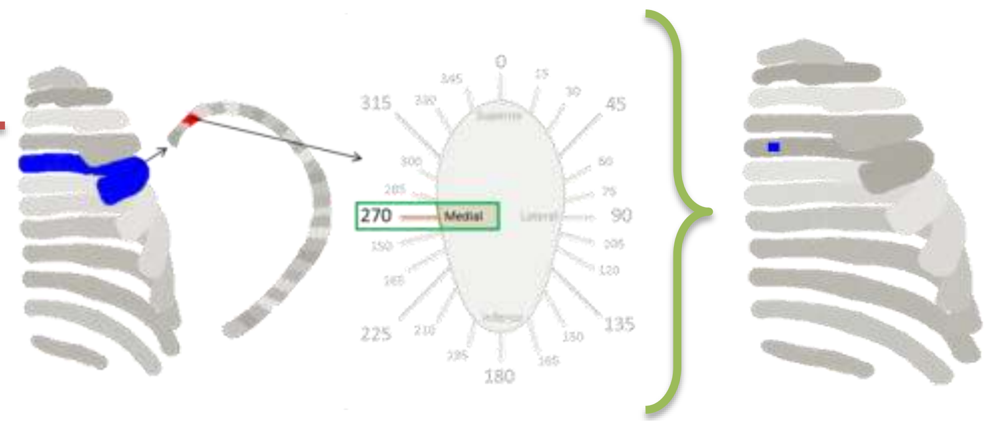
1. Computes HU value (density) from entire CT scan that best represents cortex
2. Algorithm uses density value to estimate cortical thickness over entire surface

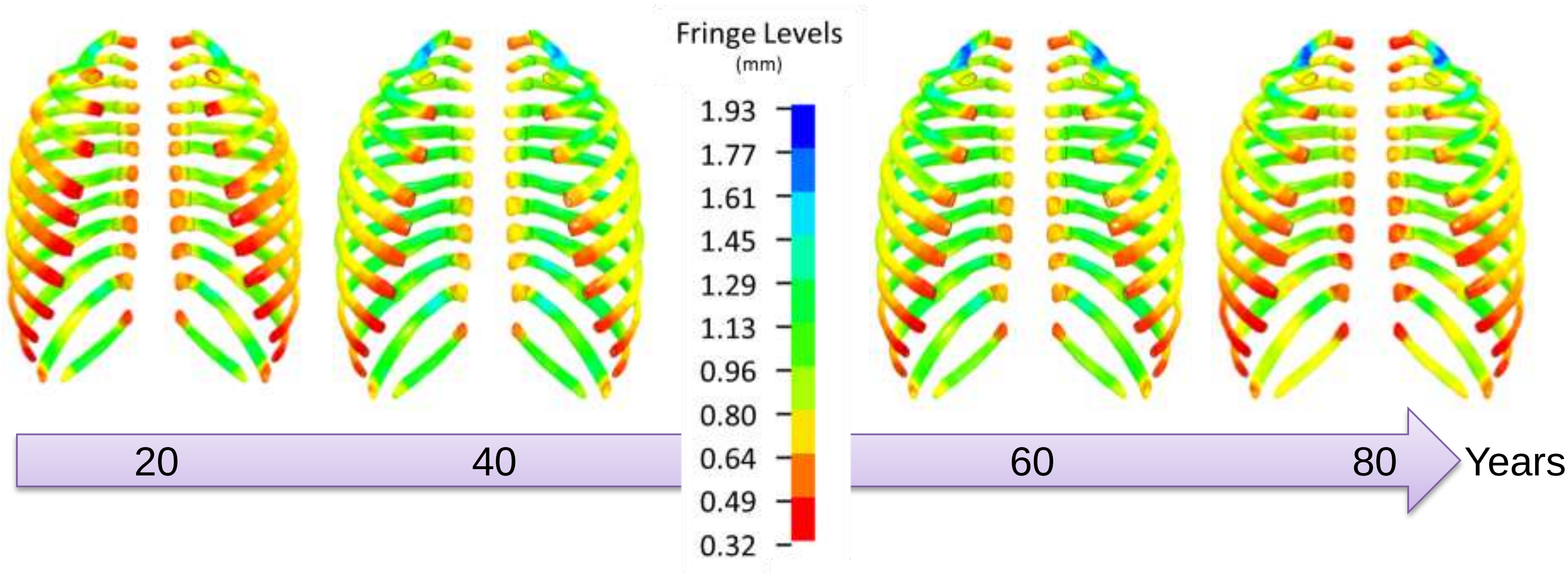


Outputs point cloud with associated cortical thickness values at each point

Rib Cortical Thickness Variation with Age

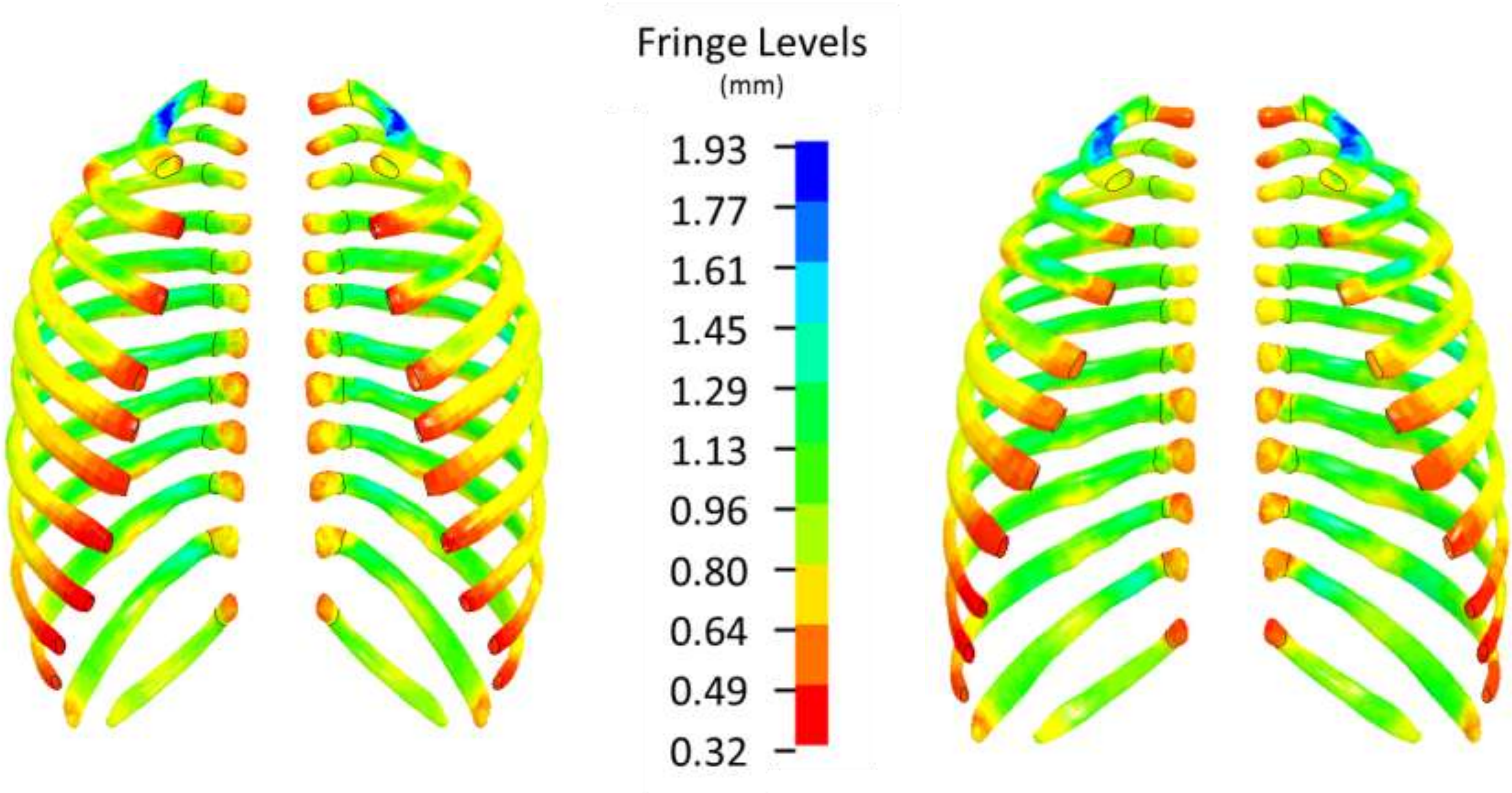






Rib Cortical Thickness Comparison

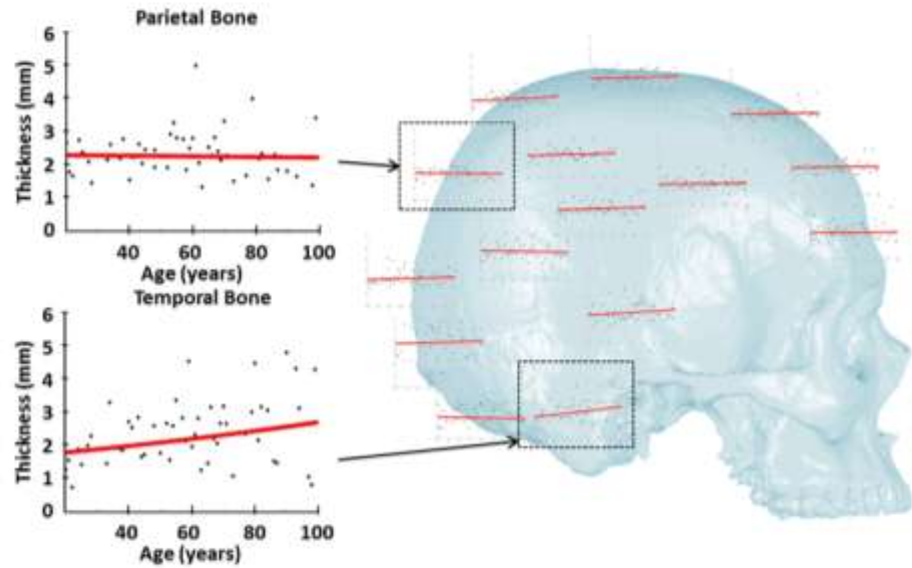
GHBMC **65yr Male**

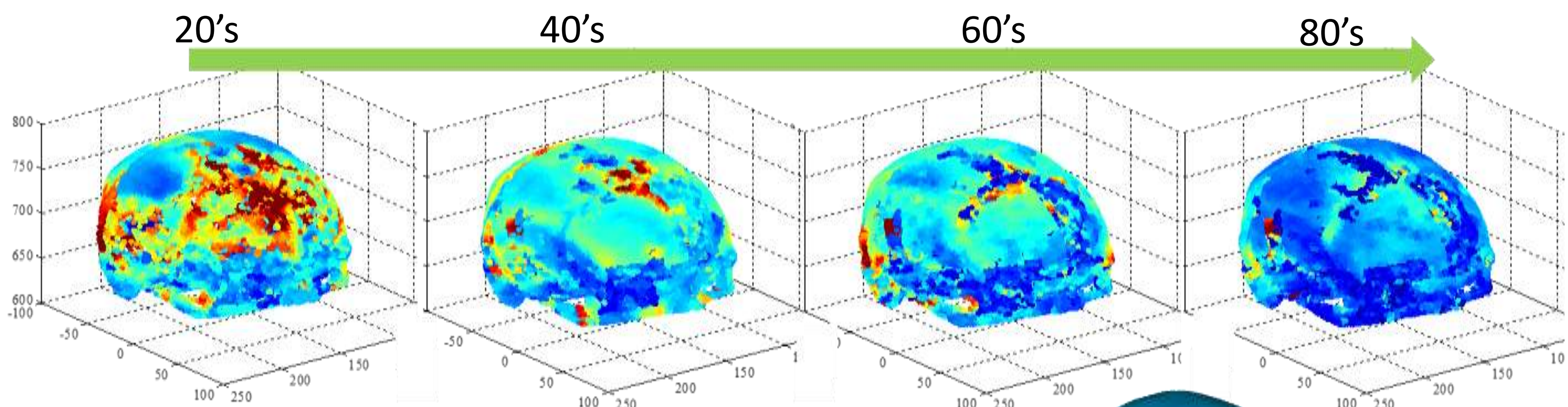


Skull Cortical Thickness Variation

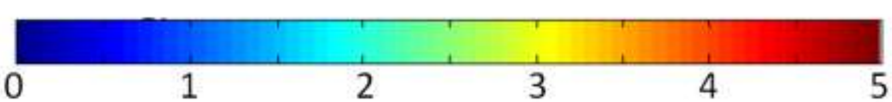
Lillie et al. (J Anatomy 2015)

Male

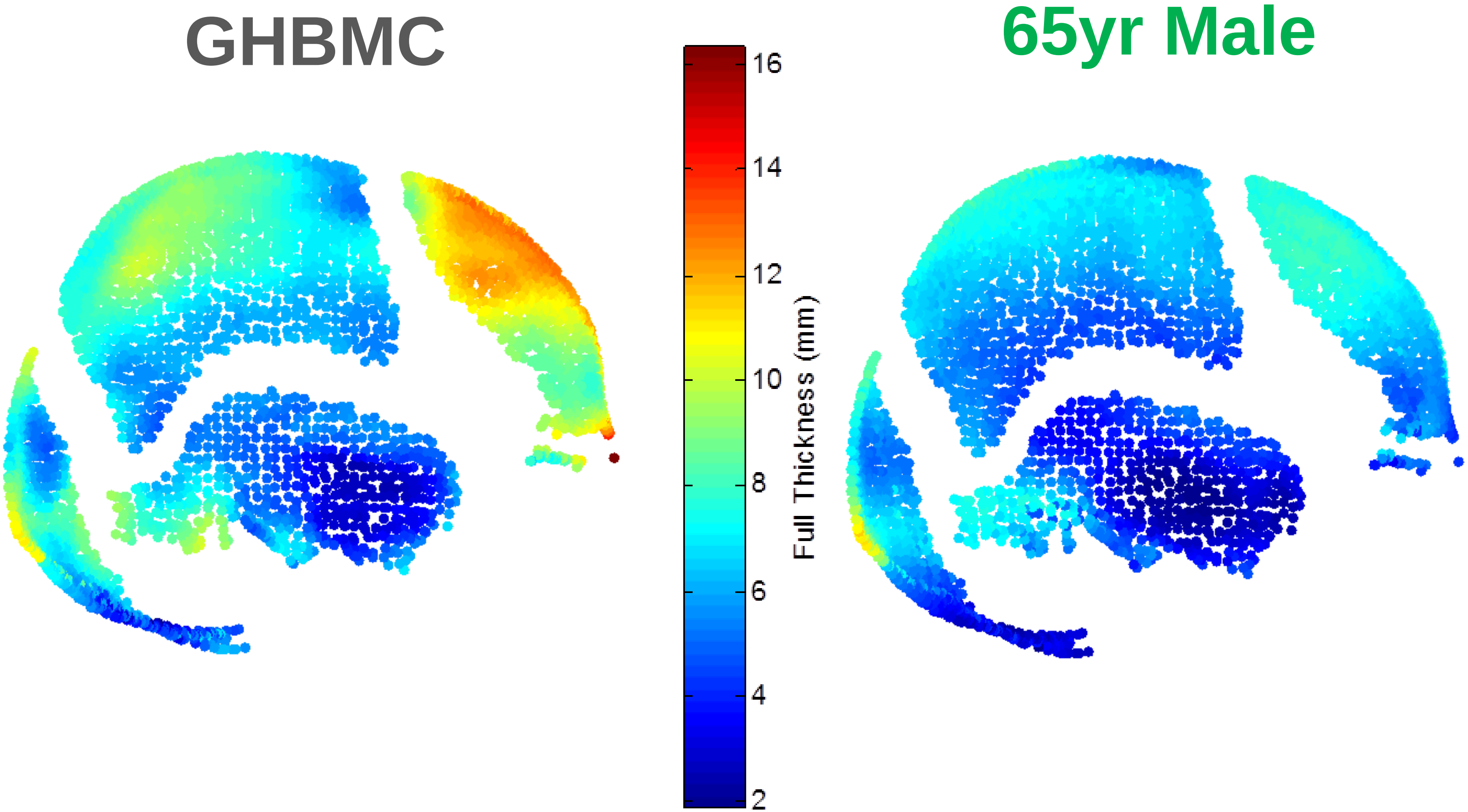




Thickness in mm



Skull Cortical Thickness Comparison



Femur Cortical Thickness Comparison

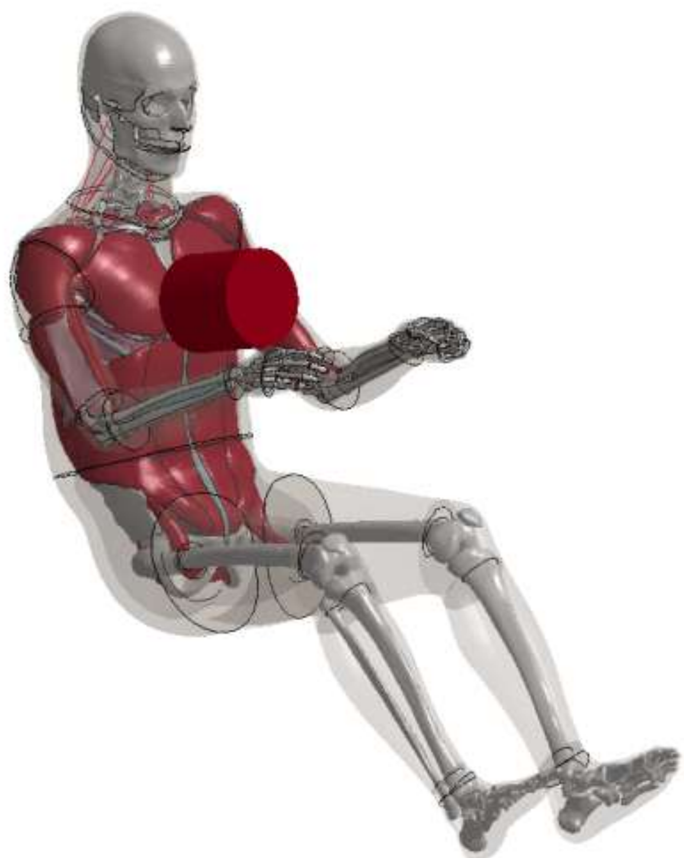
GHBMC

65yr Male

Ongoing Work

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

Ongoing Work



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

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!

www.nhtsa.gov

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

Center for Injury Biomechanics