

# Variation in Anthropometry of the Head and Chest with Age for Application to Human Injury Prediction

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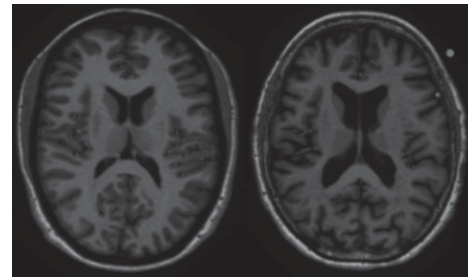
Virginia Tech-Wake Forest University Center for Injury Biomechanics  
Wake Forest University School of Medicine

## Center for Injury Biomechanics



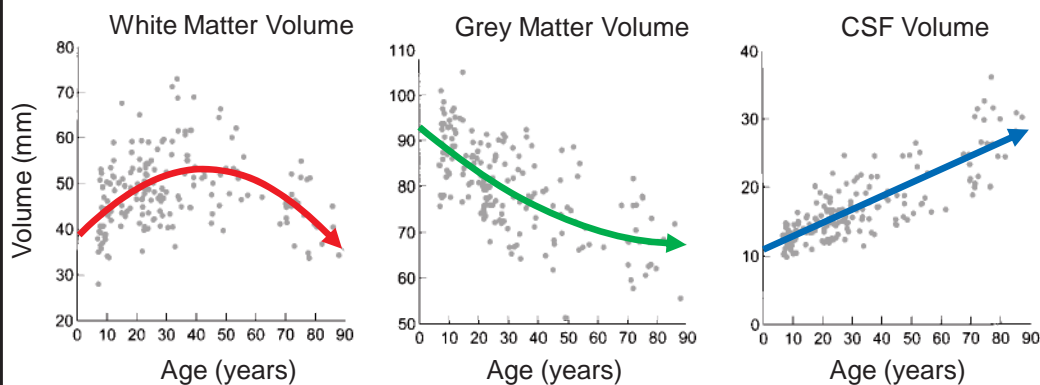
## Head Injury/Aging

- **#1 in MVC**
  - MVC = largest percentage of TBI-related deaths
  - 75 years+ have the highest rates of TBI



28 year old, female

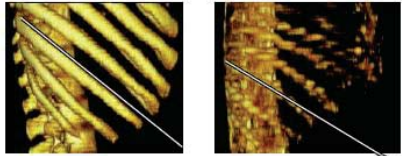
85 year old, female



Sowell et al. 2003, Nature Neuroscience

## Thoracic Injury/Aging

- **#2 in MVC:**
  - Frequency
  - Fatal/Serious Injuries
  - Economic Cost

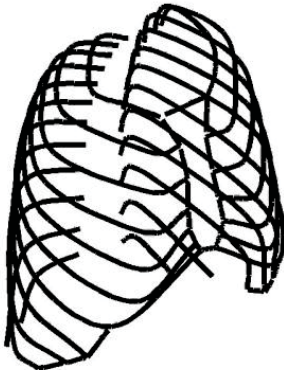


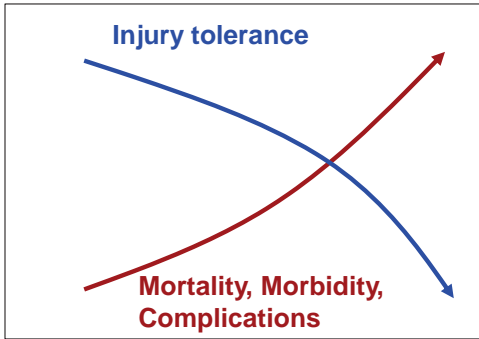
18 year-old, 50°  
rib angle

89 year-old, 57°  
rib angle

*Kent et al. 2005, Stapp*

Quadratic fit model 20 ← Age



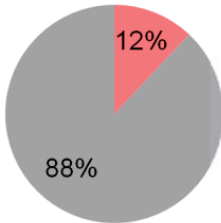


Age →

*Gayzik et al. 2008, J. Biomech*

## Increasing Elderly Population

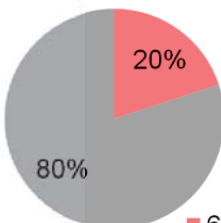
**2010**



88%

12%

**2030**



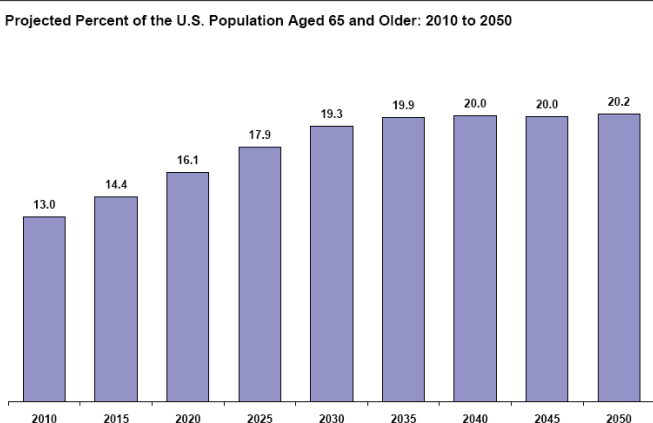
80%

20%

■ 65+ years

■ < 65 years

**Projected Percent of the U.S. Population Aged 65 and Older: 2010 to 2050**

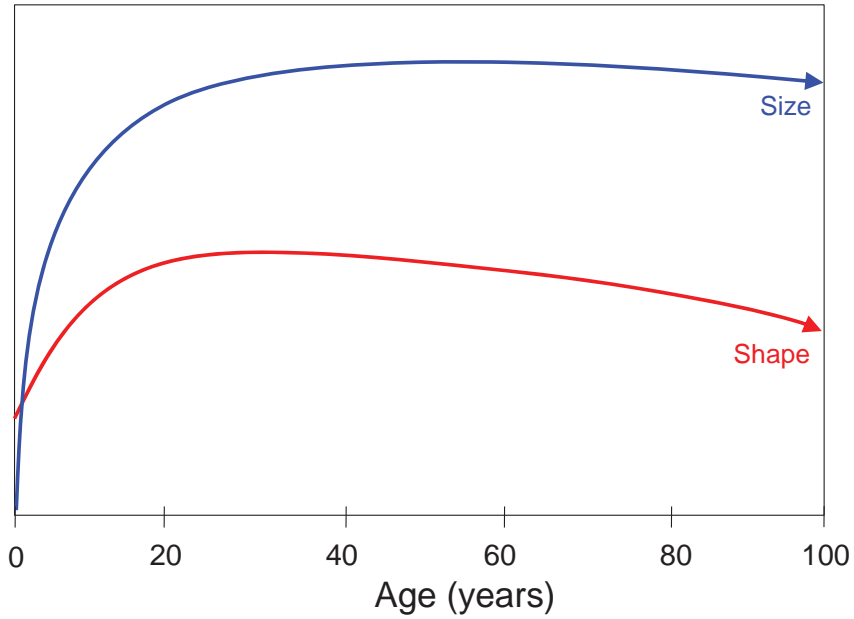


Year	2010	2015	2020	2025	2030	2035	2040	2045	2050
Percent	13.0	14.4	16.1	17.9	19.3	19.9	20.0	20.0	20.2

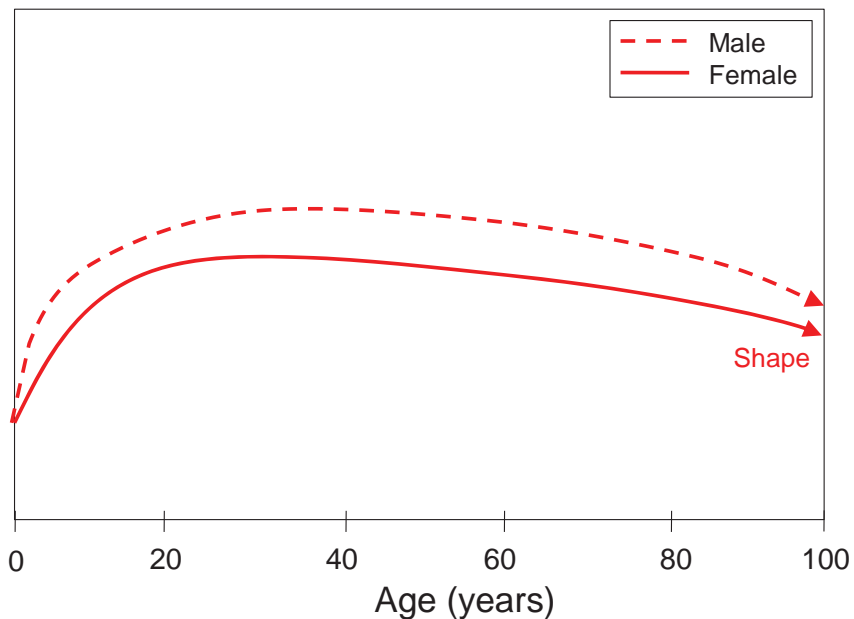
Source: Population Division, U.S. Census Bureau  
Released: August 14, 2009

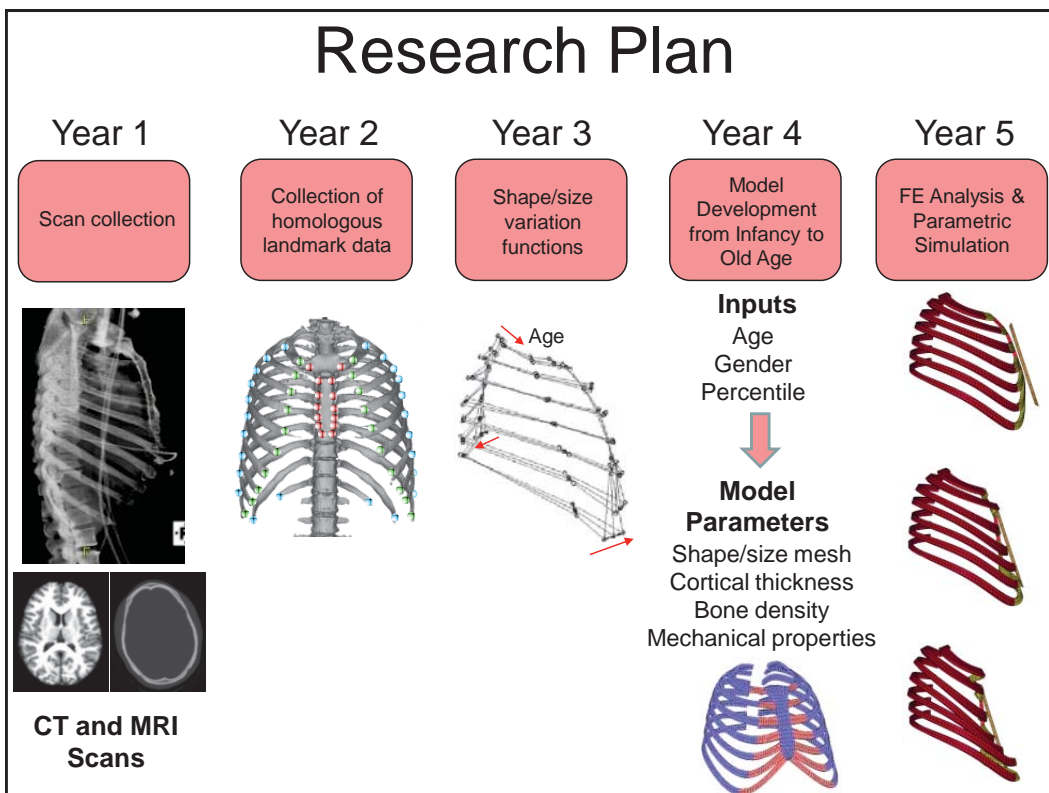
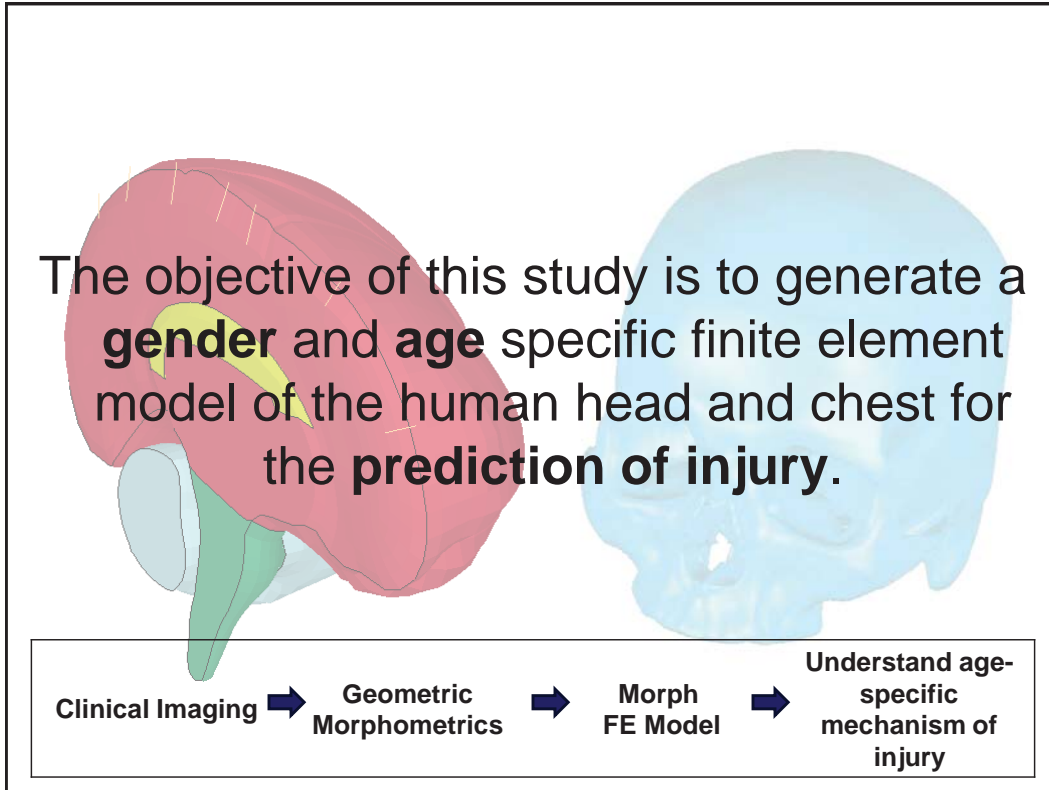
TBI and thoracic related mortality and morbidity will increase accordingly

### How Does Anatomical Morphology Change? With Age, Gender, Percentile?



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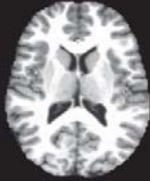




## Scan Collection

- WFU PACS system: 2006-2010, OASIS Database
- Demographic data: gender, age, weight, height, BMI
- 343 Thoracic CT Scans, 120 MRI Scans, 120 Head CT Scans

Normal MRI Scan



Normal Thoracic CT Scan



Rib cage only      Rib cage and head



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

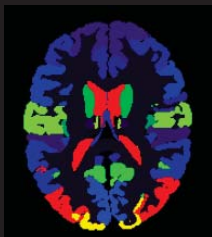
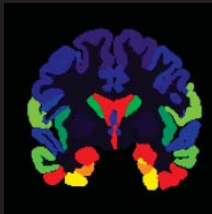
6-10 yr

80-90 yr

10-20 yr

90-100 yr

ICBM Labels

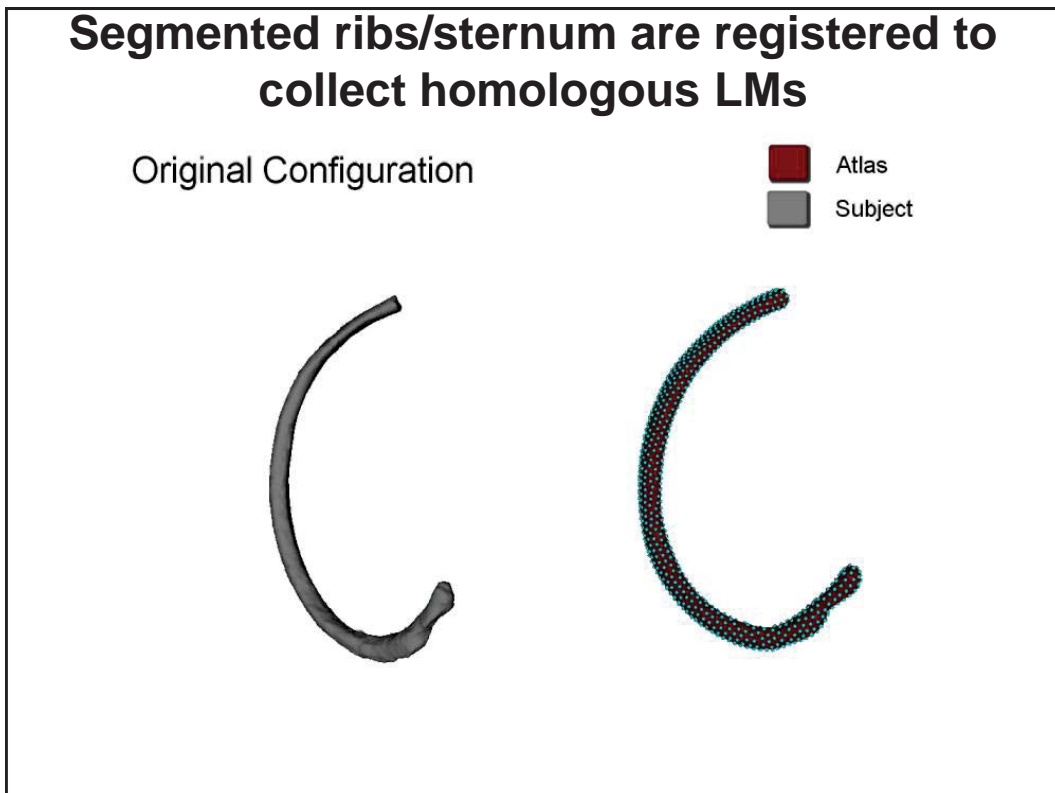
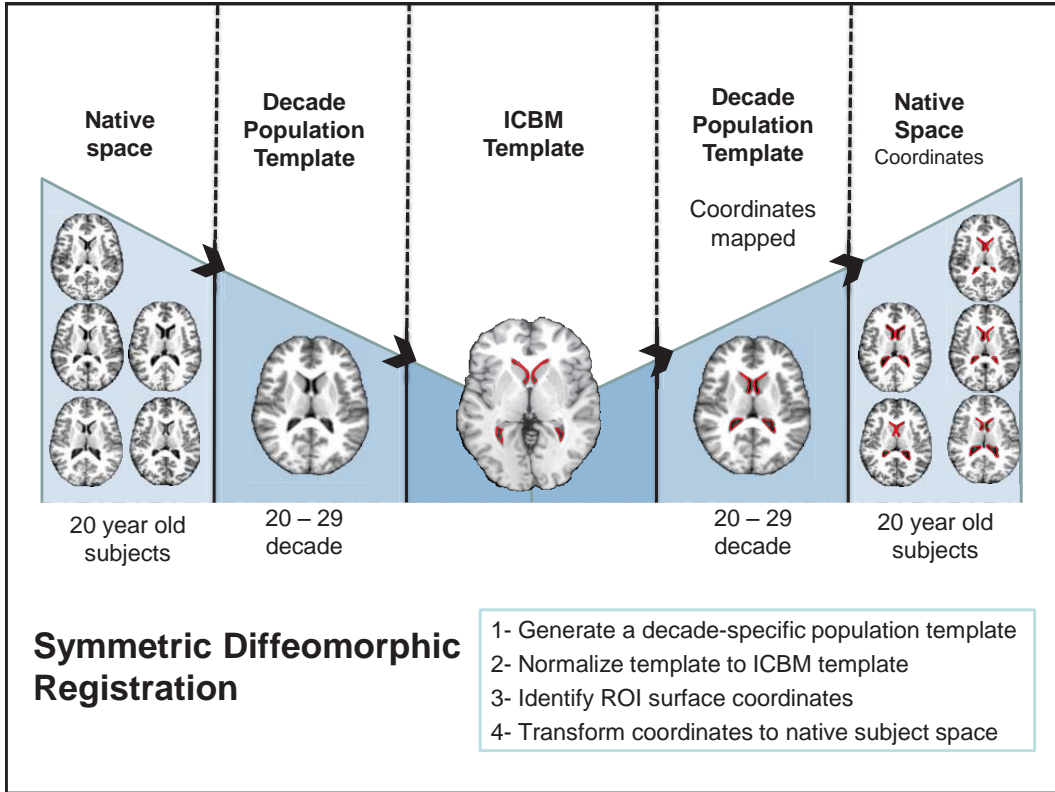


## Segmentation Methods

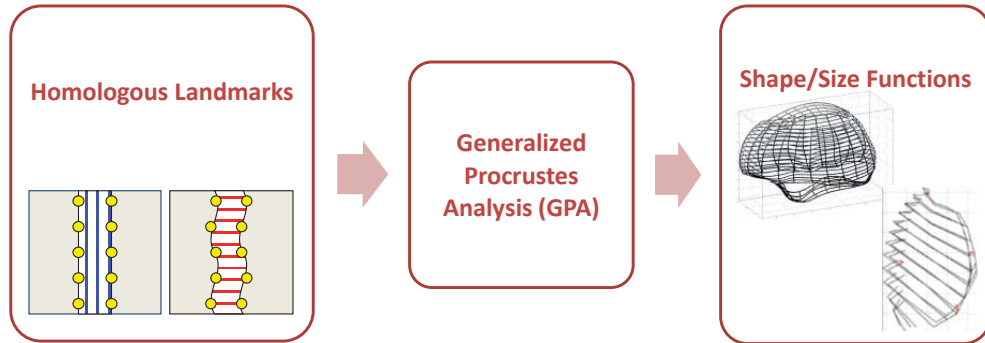
Fully –  
automated  
brain label  
segmentation

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





# Geometric Morphometrics



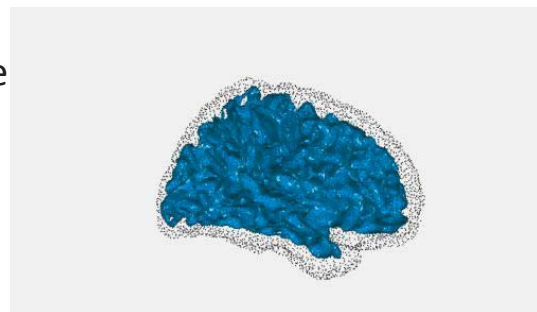
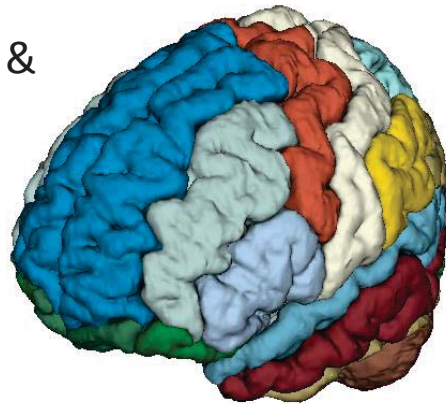
#1-3: Partial GPA (Size & Shape)

#1-4: Full GPA (Shape)

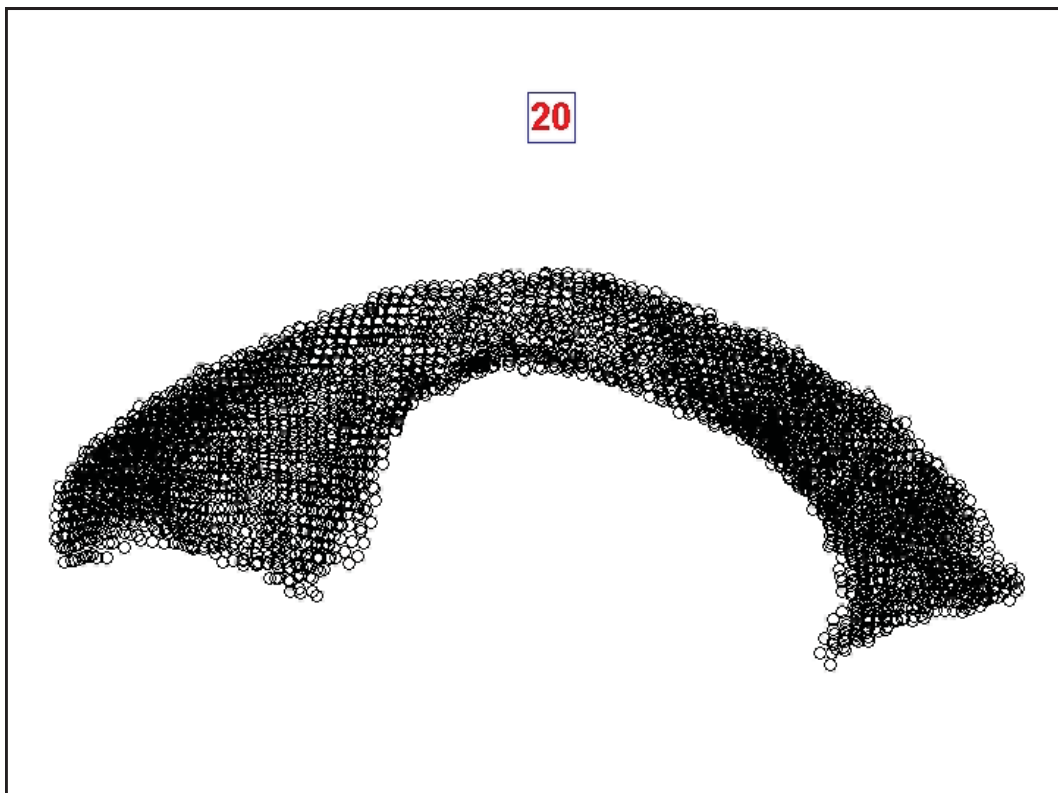
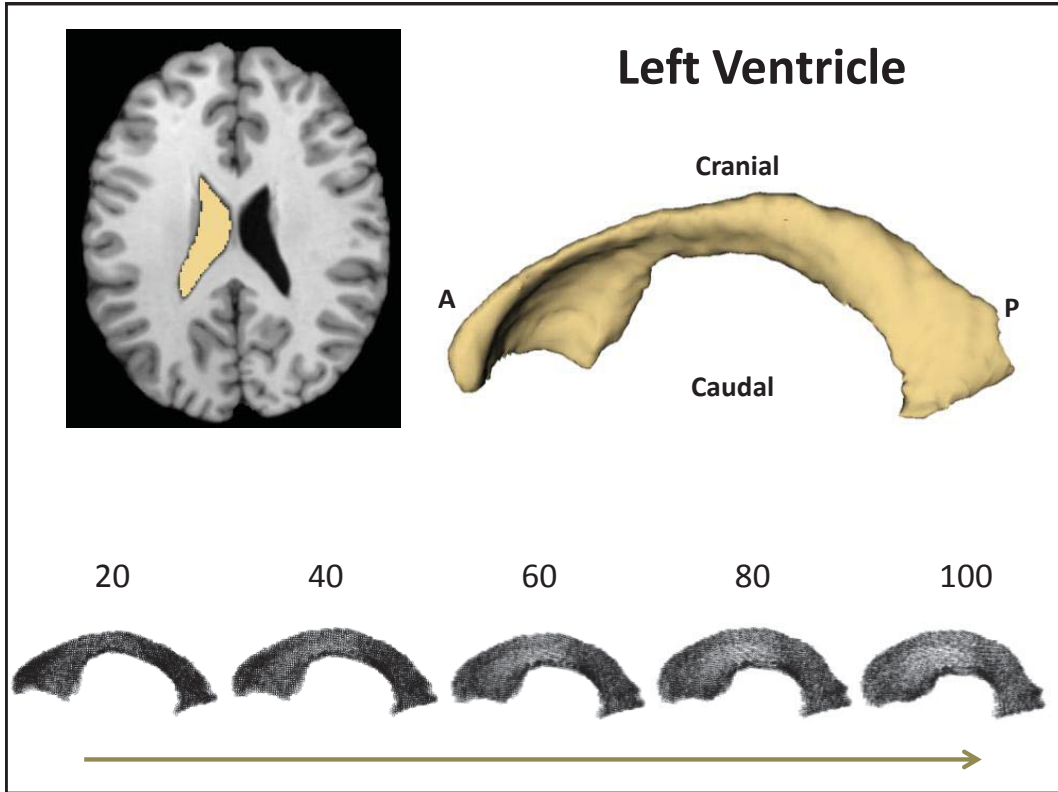
1. Initial Location <i>Points in image space</i>	2. Translation <i>Align centroids</i>	3. Rotation <i>Rotation about centroid</i>	4. Scaling (Size) <i>Dilatation or compression</i>

## Procrustes Analysis: Shape & size variation functions

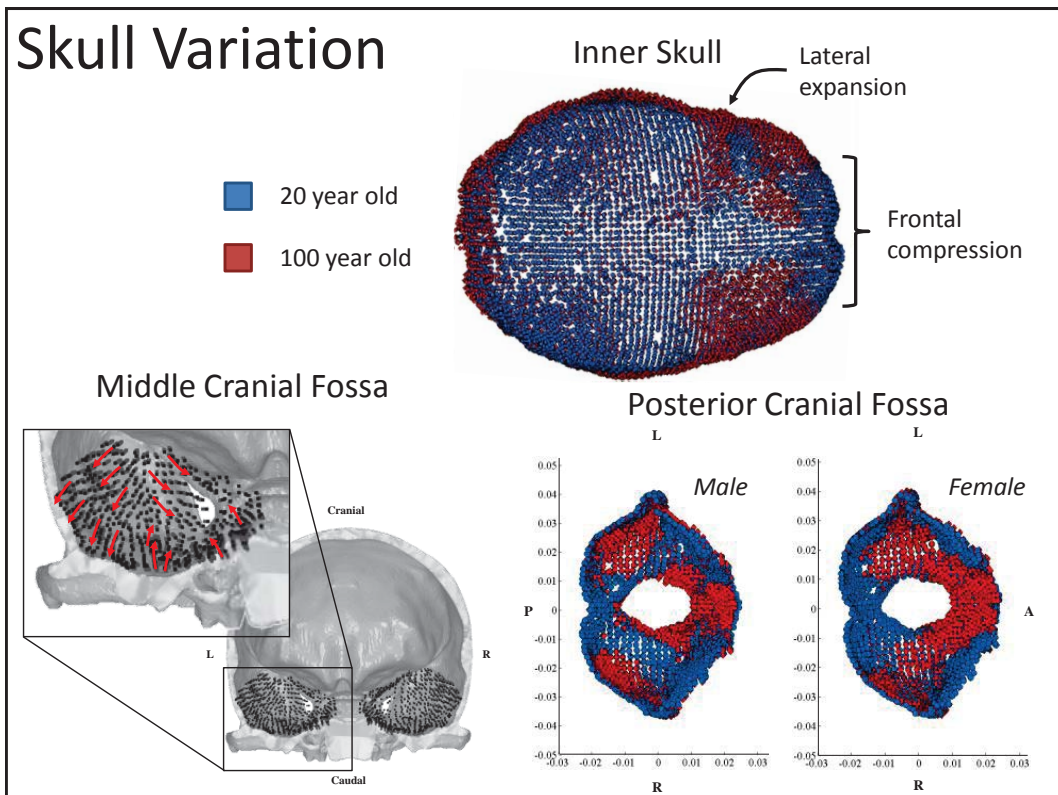
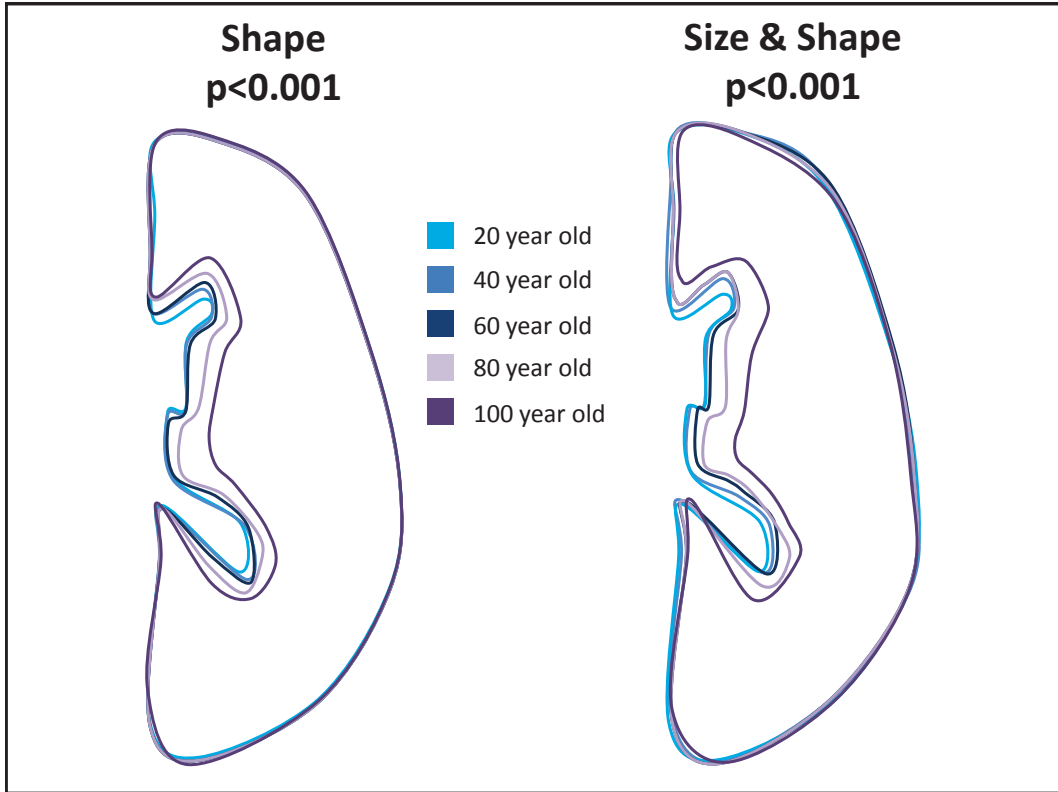
- Completed for all 48 structures in ICBM atlas + whole cerebrum & white matter
- 100% significant change in size & shape
- 100% significant change in shape



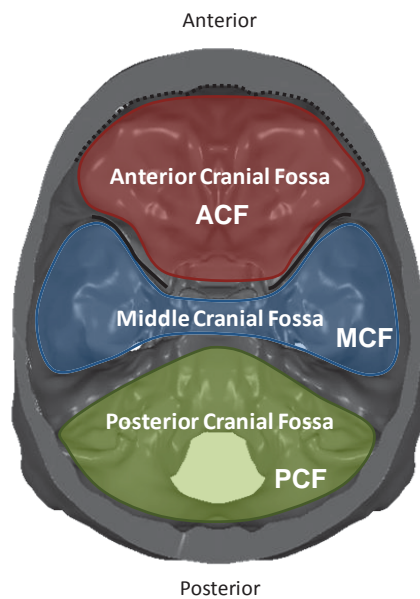








# Skull Variation Summary



- Significant changes with age in:
  - Male
    - Outer Skull ( $p=0.0333$ )
    - Inner Skull ( $p=0.0344$ )
    - ACF ( $p=0.00068$ )
    - MCF ( $p=0.00007$ )
  - Female
    - ACF ( $p=0.00016$ )
    - MCF ( $p=0.0016$ )
- No significant changes with age in **PCF**

Size/Shape  
Changes (Males)

Age Counter



000.00 years



*Similar trends in females*

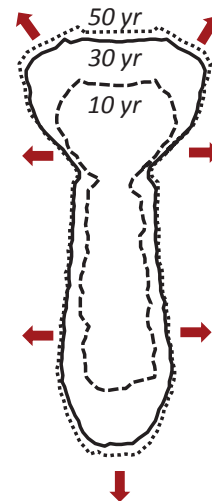
## Rib Cage Variation Summary

- Significant changes with age in each gender:
  - Rib Size & Shape ( $p < 0.0001$ )
  - Rib Shape ( $p < 0.0053$ )
- For Males and Females:
  - Age 0-20:
    - Increase in size
    - Decrease in upper thoracic kyphosis
    - Inferior rotation of the ribs
  - Age 20-60:
    - Increase in thoracic kyphosis
    - Superior rotation of the ribs
  - Age 60+:
    - Increase in thoracic kyphosis
    - Inferior rotation of upper ribs
    - Superior rotation of lower ribs



## Sternal Morphology Variation Summary

- Significant changes with age in each gender:
  - Size & Shape ( $p < 0.0001$ )
  - Shape ( $p < 0.0053$ )
- Age 0-30:
  - Increase in size
  - Manubrium:
    - Lateral/superior expansion
    - Widens in relation to sternal body
    - Transforms from circular to oval shape
  - Sternal body:
    - Lateral/inferior expansion
    - Distal portion wider than proximal portion
- Ages 30+: Minimal changes in size or shape
- Most changes occur when cartilaginous sternum is ossifying/fusing



# Quantifying Cortical Thickness of Ribs and Skull with Age

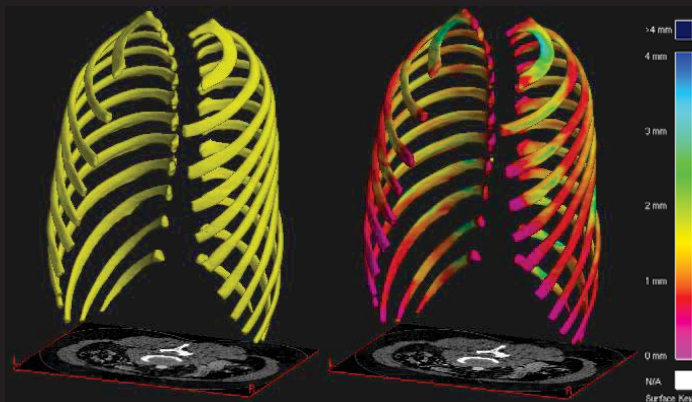
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## Cortical Thickness Estimation (Stradwin)

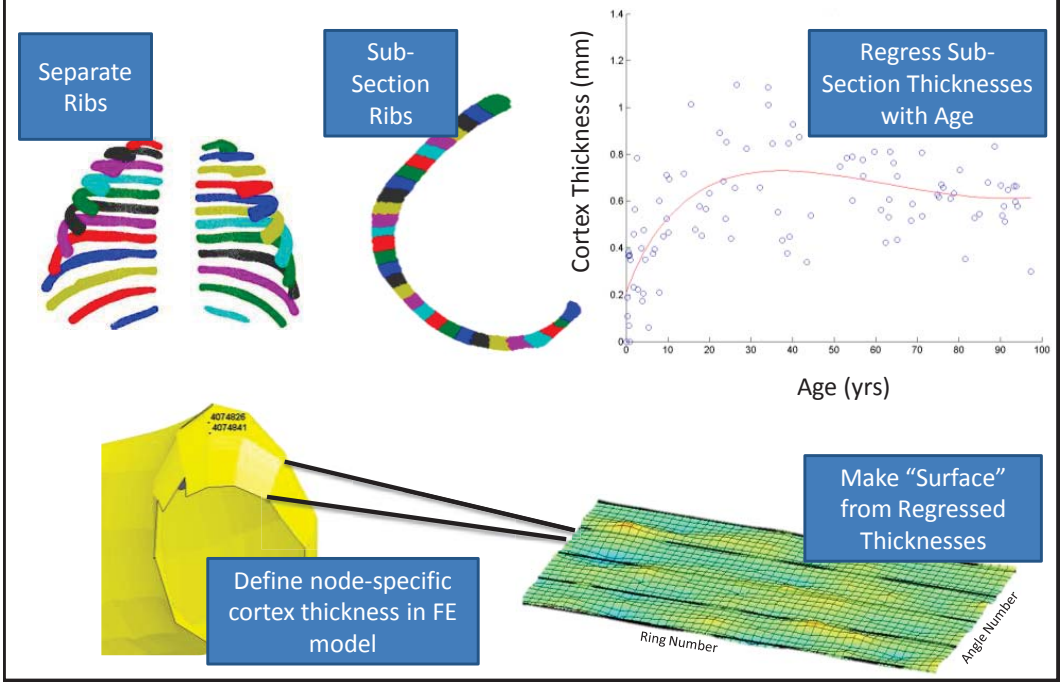
*Treese et al. 2010, 2012*

1. Computes an approximate HU value (density) from entire CT scan that approximates cortex
2. Algorithm uses HU value to estimate cortical thickness over a surface

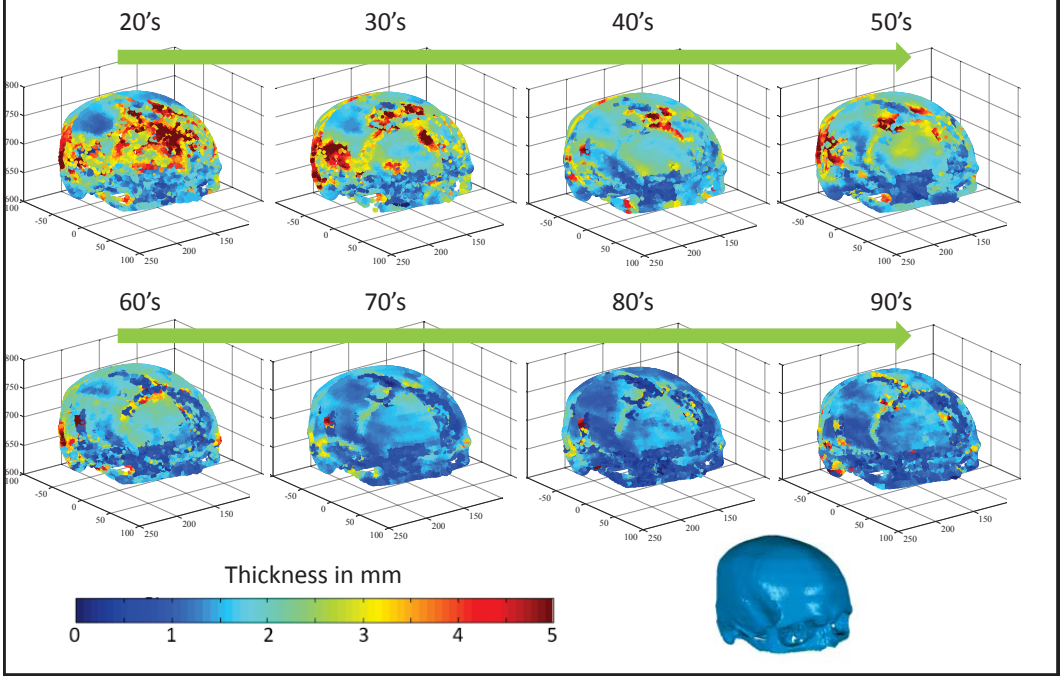


Outputs point cloud with associated cortical thickness values at each point

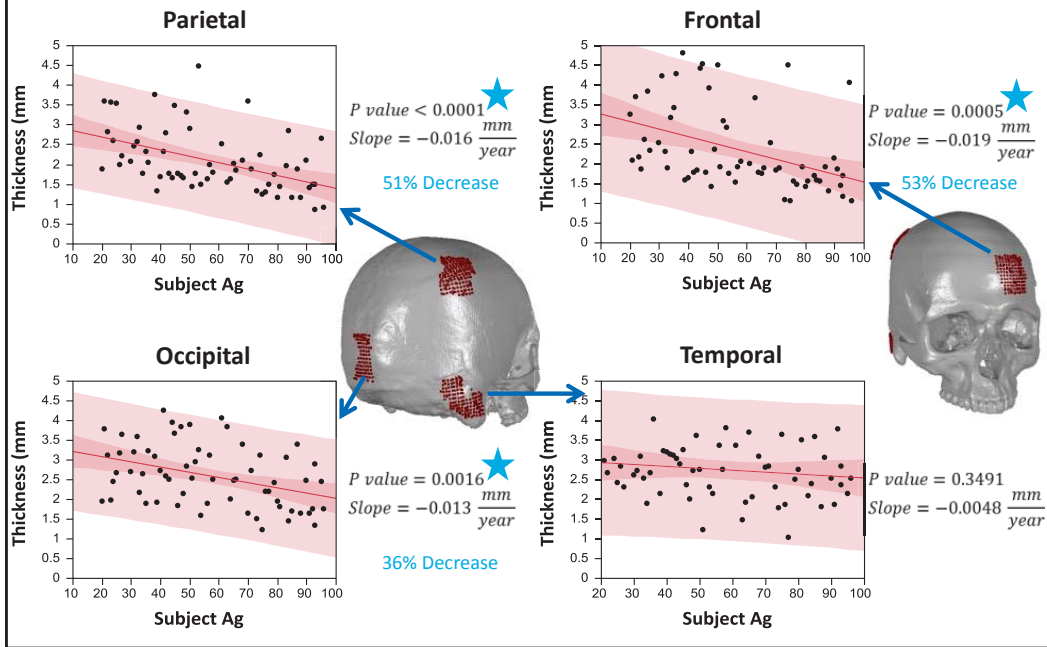
# Rib Cortical Thickness Workflow



# Skull: Outer Table Thickness With Age



## Skull: Outer Table Thickness with Age for Females



## Modeling Efforts

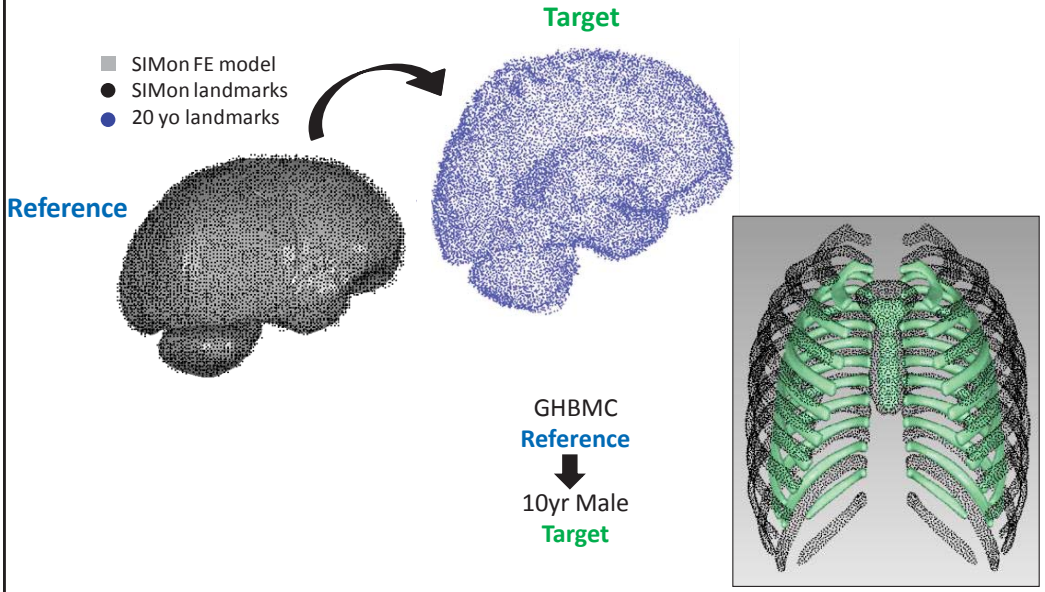
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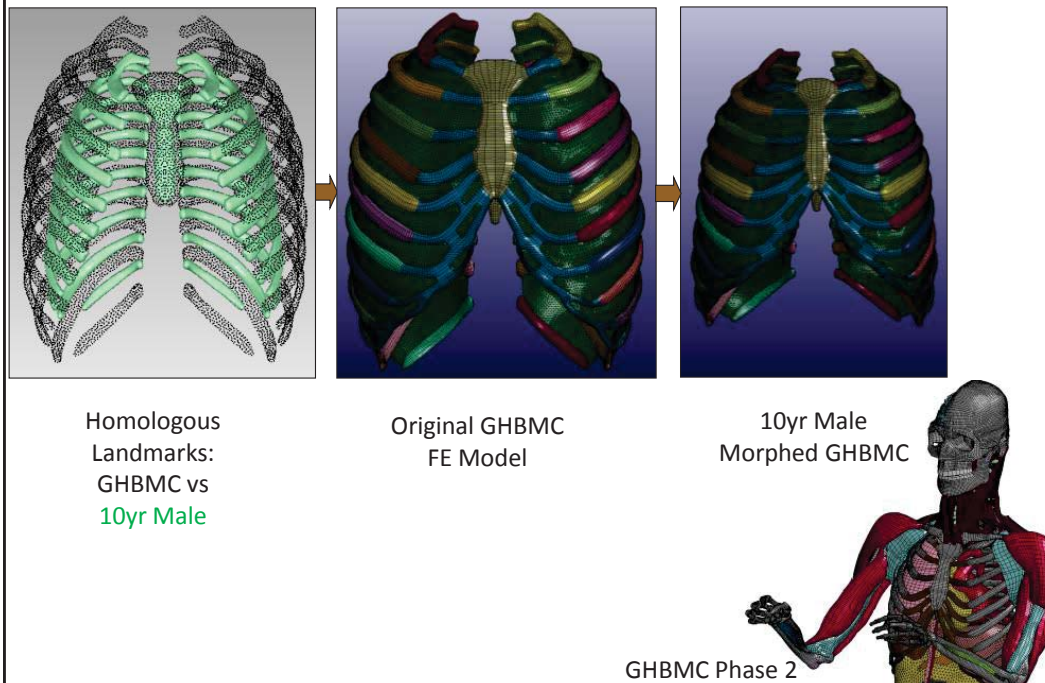


# Morphing Methods

- Compute the Bending Energy Matrix between the reference configuration and the target configuration



## Age and Gender-specific FE Models





## Innovation

- Segmentation & Registration Algorithm
  - Improved method to collect extensive homologous LM data
  - Application of brain registration algorithms to collect LMs from the brain, skull, and rib cage
  - Semi-automated, 3D morphing
  
- Morphology Characterization (GPA)
  - Brain: 120 subjects, 48 independent brain labels, 20-94 yrs, M/F
  - Skull: 120 subjects, 20-100 yrs, M/F
  - Rib Cage: 343 subjects, 0-100 yrs, M/F

Results lead to an improved understanding of the complex relationship between head & thoracic anthropometry, age, gender, and injury risk

## Thank you



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



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 Wake Forest  
 School of Medicine



Virginia  
 Tech  
 COLLEGE of ENGINEERING

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