Mesh morphing for the mid-size male GHBMC pedestrian model to represent obese subjects

Jisi Tang[1, 2], Qing Zhou[1], Katelyn F. Klein[2], Daniel Byoung-Keon Park[2], and Jingwen Hu[2]

1 State Key Laboratory of Automotive Safety and Energy, Tsinghua University, Beijing, China

2 University of Michigan Transportation Research Institute, Ann Arbor, MI, USA

Background

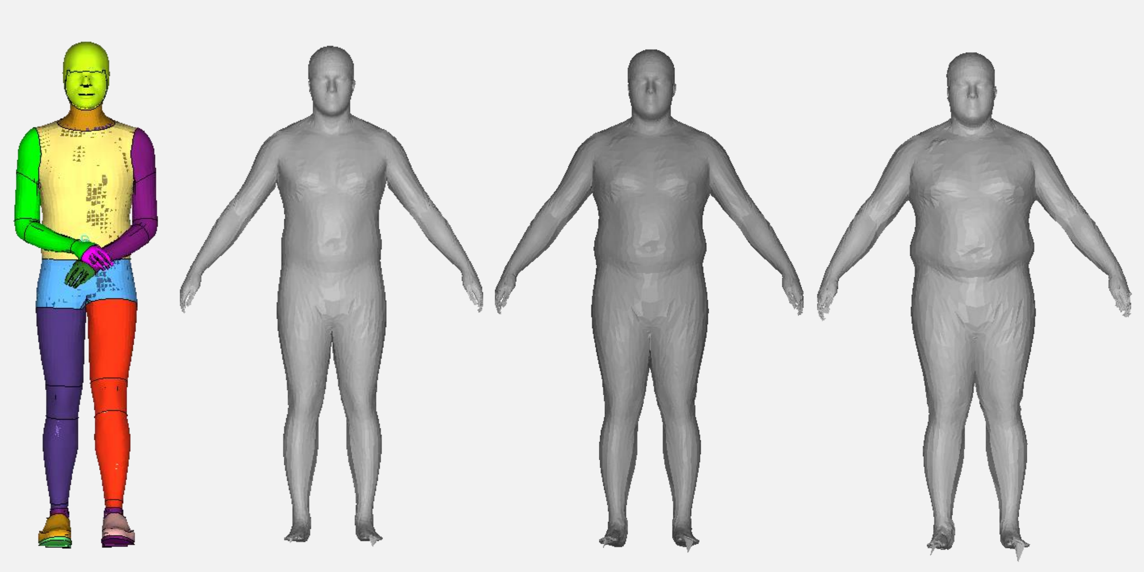
Lower extremities are the most frequently injured body region in vehicle-to-pedestrian crashes, accounting for 41% of all AIS 2+ level injuries for pedestrians, and their injury risk is highly related to human characteristics, such as stature, BMI and age. In the past 30 years, the prevalence of obesity across the U.S. had increased significantly. However, current pedestrian human body models, such as GHBMC and THUMS only represent pedestrians with limited body size and shape and do not consider the obesity effects.

Objective

The objective of this work is to develop a method to morph the mid-size male GHBMC pedestrian model into pedestrians with a wide range of human attributes.

Methods

UMTRI has developed parametric human body modeling method for seated occupant in past years. The current study applies similar techniques for morphing the GHBMC mid-size male pedestrian model into obese pedestrians. BMI 35 was selected as an example to show the detailed morphing process.



Target geometry for obese pedestrian models

➢ Statistical geometry models

Statistical external body shape [1] and lower extremity skeleton models [2] were developed previously. Body surface scan data was collected by laser scanner of ~200 subjects. Skeleton geometry for the lower extremity is reconstructed from CT scan data. There were 116, 98 and 76 subjects for pelvis, femur and tibia, respectively. Three main steps were involved in statistical geometry model generation:

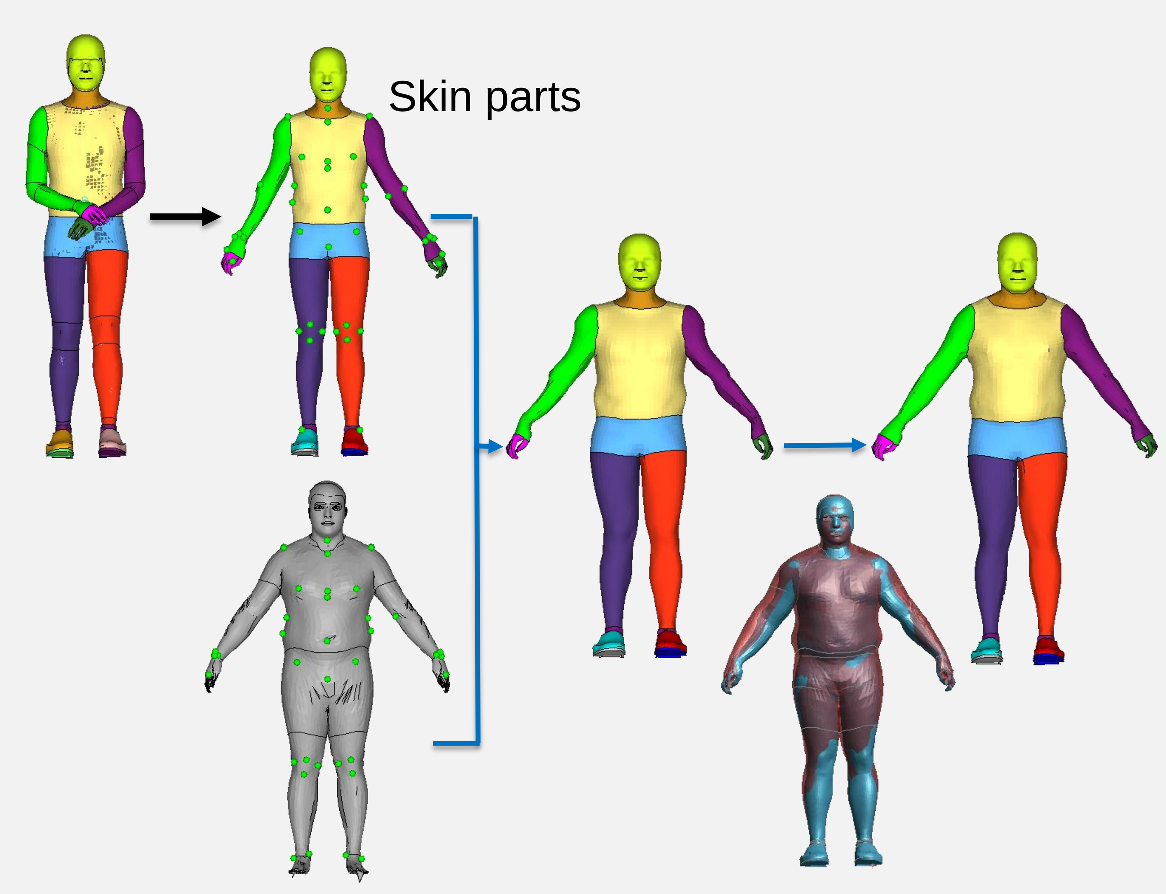
1. Generalized Procrustes Alignment (GPA)
2. Principal Component Analysis (PCA)
3. Regression Analysis

Finally the external body shape and lower extremity bone geometry can be predicted by a given set of anthropometric parameters, including height, BMI, age and gender.

➢ Posture adjustment and mapping for skin mesh

Due to the posture difference between the baseline GHBMC model and the target statistical model, the GHBMC model should be repositioned to make the mesh morphing process feasible. Pre-simulation in LS-DYNA is chosen for posture adjustment rather than direct morphing accounting for more realistic anatomical assembly and element deformation in joints.

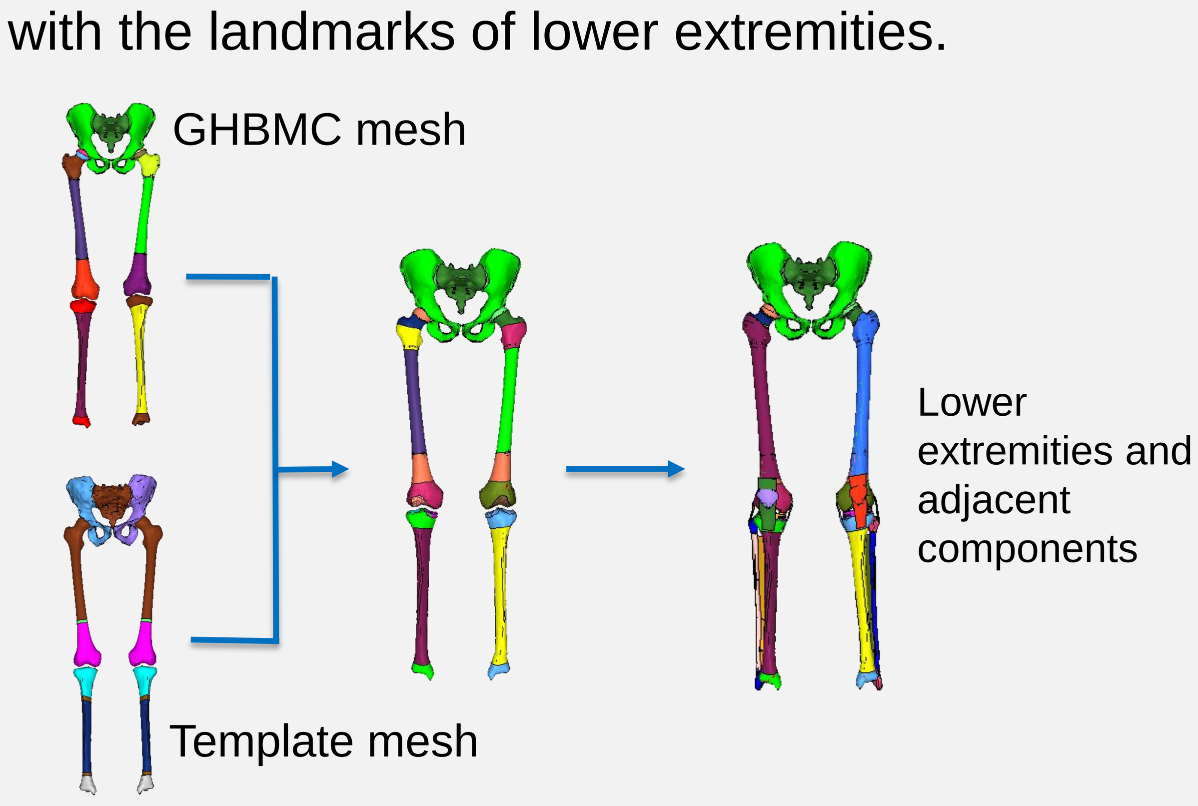
The external surface mesh of the GHBMC was morphed into the geometry targets based on 45 landmarks defined in the SBSM by a radial basis function using thin-plate spline (RBF-TPS). The morphed mesh was then further projected onto the geometry surface predicted by the SBSM.



Pre-simulation in LS-DYNA, mapping and mesh morphing for skin elements

➢ Bone geometry mapping

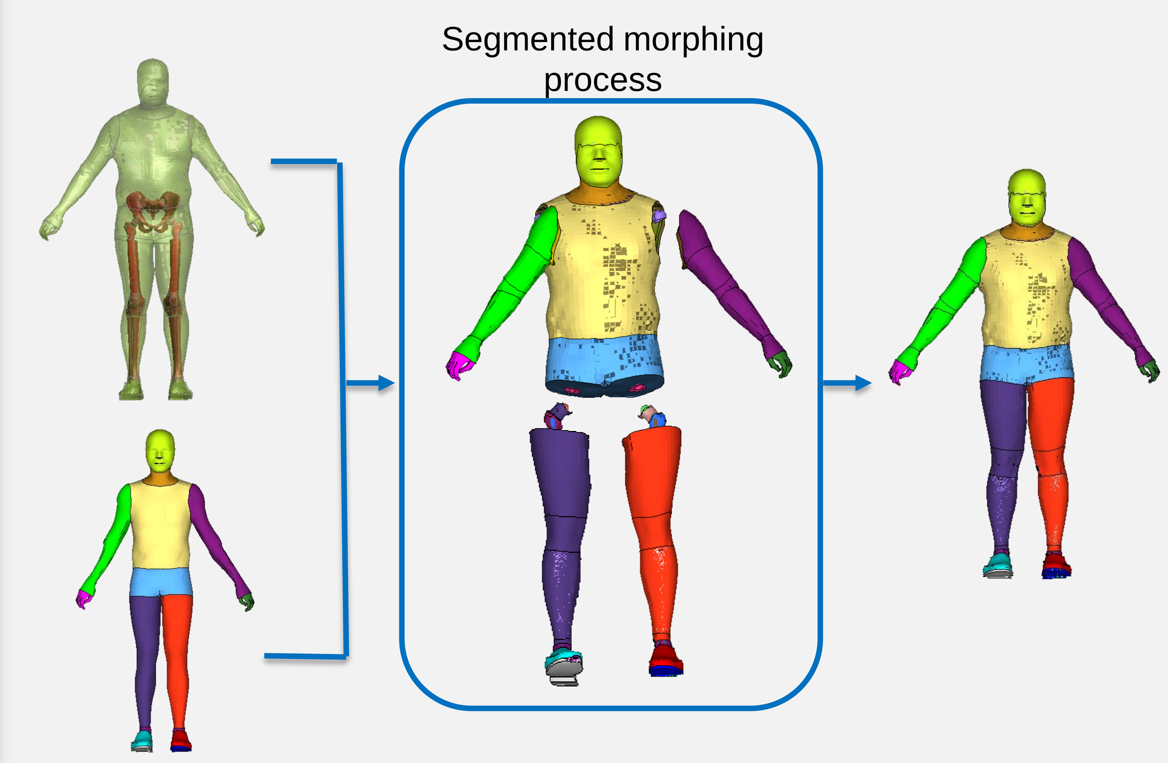
The pelvis, femur, and tibia surface meshes from the GHBMC were morphed/projected onto the geometry targets using the same method with skin mesh. Adjacent components, including ligaments, menisci, and fibula were subsequently morphed with the landmarks of lower extremities.



Mapping and mesh morphing for bone structures

➢ 3D whole body mesh morphing

All the nodes in the GHBMC pedestrian model were morphed based on the landmarks on external surface mesh and lower extremity bone meshes. The bones were positioned based on the landmarks on the external body shape model. To conduct the mesh morphing more efficiently, the GHBMC model was divided into five body regions, including the head and torso, two upper extremities and two lower extremities.



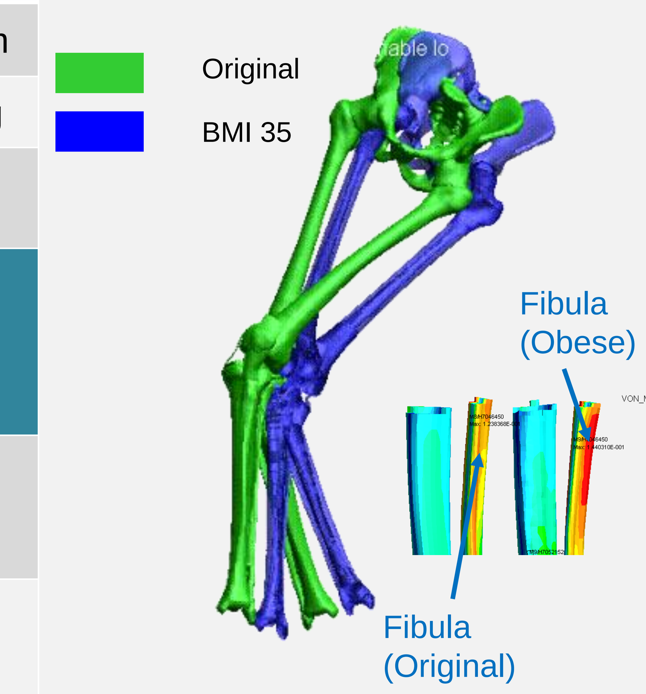
Segmented whole body mesh morphing process

Results and discussion

As an example, a pedestrian model with stature=1750mm and BMI=35 was generated. The mesh quality of the morphed model was similar to the original GHBMC pedestrian model. Risk of fibula rupture was much higher for obese pedestrian in preliminary simulation.

	BMI 35	GHBMC
Stature	1.75 m	1.749 m
Weight	107.2 kg	76.9 kg
Predicted Weight	102.4 kg	
Minimum Jacobian for elements (0.3 for solids and 0.6 for shells)		
Torso	0.34 (0% failed)	0.40 (0% failed)
Arms	0.47 (0% failed)	0.47 (0% failed)
Legs	0.32 (0% failed)	0.40 (0% failed)

Mesh quality



Original: 123. 84 MPa, 25 ms
BMI 35: 144.03 MPa, 25 ms

Stress distribution of fibula

Conclusions and future work

The present study developed a detailed method for morphing the mid-size male GHBMC pedestrian model into a specific set of anthropometric parameters. Such method can enable future studies focusing on quantifying effects from human characteristics on pedestrian lower extremity injuries.

Acknowledgement

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References

1 Park, B.-K., & Reed, M. P. (2015). Parametric body shape model of standing children aged 3–11 years. Ergonomics, 58(10), 1714–1725.

2 Klein, K. F., Hu, J., Reed, M. P., Hoff, C. N., & Rupp, J. D. (2015). Development and Validation of Statistical Models of Femur Geometry for Use with Parametric Finite Element Models. Annals of biomedical engineering, 1-12.