Toward Improved Safety Equity: An Efficient, Parametric and Posable Finite Element Human Model Representing a Diverse Population

Jingwen Hu, Mayank Dhawan, Xuanrui Fan, Matthew Reed

I. INTRODUCTION

Field data analyses have shown substantial safety equity issues in motor-vehicle crashes, such as those between men and women, old and young, and occupants with and without obesity. Finite element (FE) human body models (HBMs) have the potential to help address these safety equity problems in ways that cannot be addressed by anthropomorphic test devices (ATDs) [1]. However, conventional FE HBMs have several limitations. First, they are typically developed based on the geometry from single subjects. Consequently, models with approximately the same reference stature and weight contain substantially different geometry. Second, only a few adult body sizes are available, which account for only a small amount of the morphological variations in skeleton and external body shape among the population. Third, state-of-the-art HBMs typically require long computational time for posturing and crash simulations, which limits the utility of these models for restraint system optimization. To address these limitations, we present a new parametric human modeling framework that emphasizes efficiency and flexibility. The new framework is demonstrated through population-based simulations using a large set of diverse HBMs.

II. METHODS

Model Development

In prior work, we presented a framework for parametric human modeling in which a baseline model was morphed to represent a wide range of human body sizes [2-3]. Figure 1 shows the application of this approach to the development of a new baseline HBM, known as the Human Element-based Model for Enhanced Safety (HERMES™). Statistical models of skeleton (neck, ribcage, pelvis, femur and tibia) and external body shape developed in our laboratory over the past 10 years are used to predict the geometry for the target body dimensions. A mesh morphing method links the baseline mesh to the statistical geometry targets, so that the morphed models can represent individuals with a wide range of body size and shape. Material properties are defined based on the literature. A mesh morphing method is used to rapidly reposition any morphed model into different postures for crash simulations.

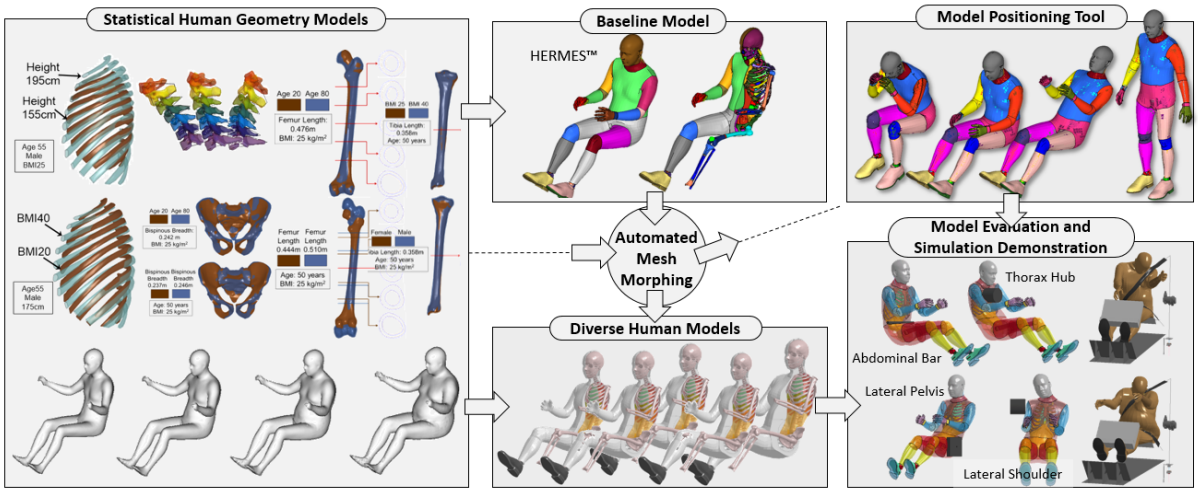

Fig. 1. Framework for developing the efficient, parametric and posable human model.

Model Evaluation and Simulation Demonstration

A population of 50 male and 50 female HBMs were generated, representing a wide range of stature and body weight. Each model has the same mesh topology, with approximately 220,000 elements. The mesh quality varied slightly among HBMs but was generally comparable to the baseline model. The morphing process for creating each HBM took <5 minutes. With a 0.9-µs time step, a 100 ms impact simulation takes <30 minutes to run on a

J. Hu (e-mail: jwhu@umich.edu) and M. Reed are research faculty members at the University of Michigan Transportation Research Institute. M. Dhawan and X. Fan are Master students at the University of Michigan, Ann Arbor, MI, USA.

contemporary desktop PC.

Population-based simulations were conducted with the models in a variety of impact conditions, including a 23 kg hub impact to the thorax with an initial velocity of 6.7 m/s, a 48 kg bar impact to the abdomen with an initial velocity of 6 m/s, a 23 kg pendulum lateral impact to the right shoulder with an initial velocity of 4.5 m/s, and a lateral pelvis impact with an initial velocity of 10 m/s. The simulation results were compared to the cadaver test corridors developed for the 50th percentile male. In addition, a frontal impact condition was also simulated at 32 kph with a load-limiting seat-belt but no airbag to verify the model robustness.

III. INITIAL FINDINGS

Impact simulation results at five loading scenarios are shown in Fig. 2, overlaid with the midsize male corridor. As the 100 HBMs are of varied size and weight, the intent of this comparison is not to validate the diverse HBMs but to demonstrate the capability of conducting population-based simulations. It is interesting to note that response variations are loading-specific and may be different between male and female.

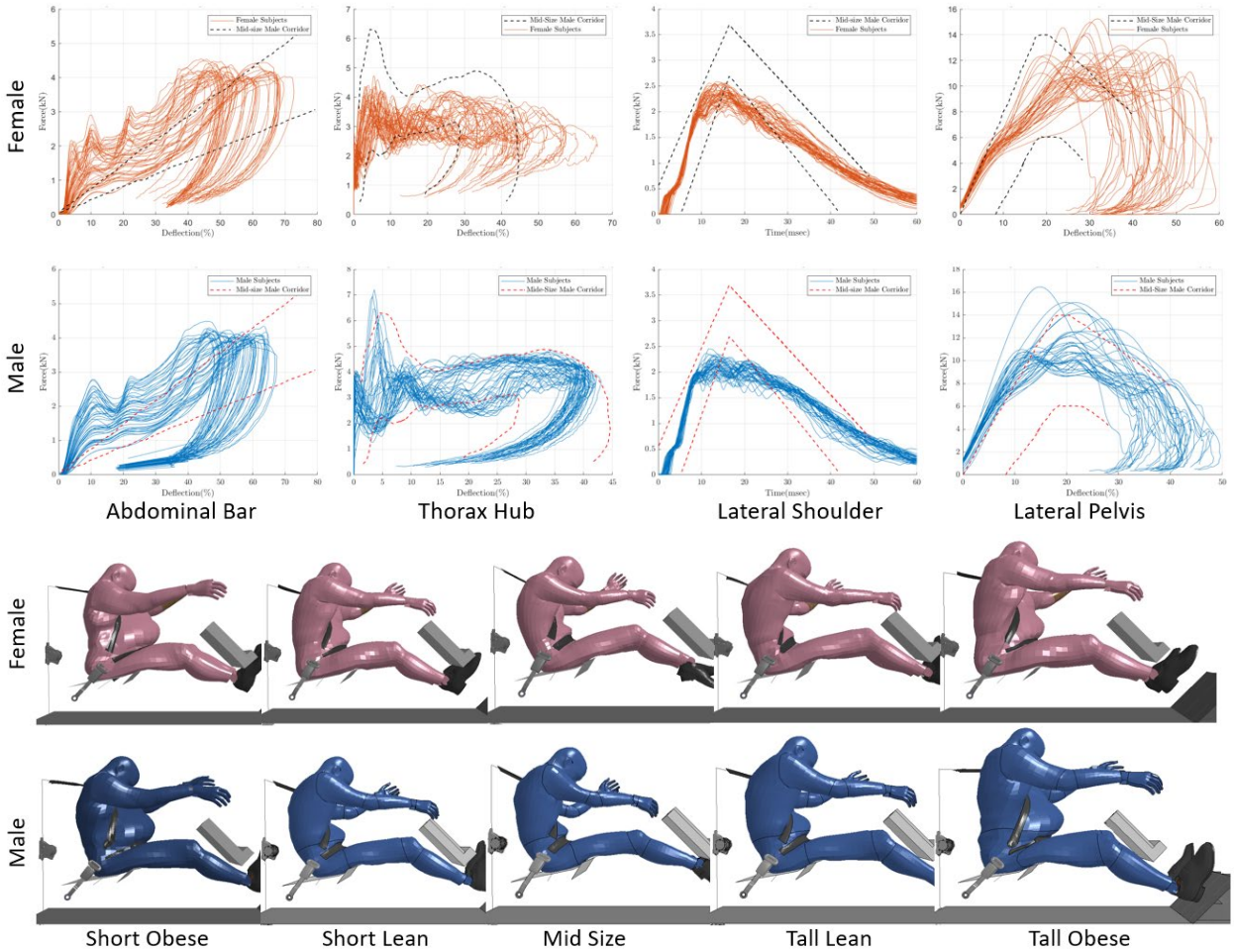

Fig. 2. Exemplar simulation results of 100 diverse HBMs under five loading scenarios.

IV. DISCUSSION

The new HERMES™ model is the first HBM developed specifically to be morphed to a wide range of body sizes and shapes, enabling efficient population-based simulations. Preliminary simulations show good efficiency and robustness. Model validity can be further improved through subject-specific model validations against cadaver tests [4]. The diverse HBMs shown here could serve as a tool to address safety equity issues in crashes and to enable better understanding of which occupant may have the potential to drive the restraint systems into different locations from the current injury assessment tools, which focus only on midsize male and small female.

V. REFERENCES

[1] Hu, J., *et al*. *Traffic Inj Prev*, 2019, pp.S97–S105.
[2] Hwang, E., *et al*., *Stapp Car Crash J*, 2016, p.473–508.
[3] Zhang, K., *et al*. *J Biomech*, 2017, p.253–260.
[4] Zhang, K., *et al*. *Obesity*, 2017, pp.1786–1794.