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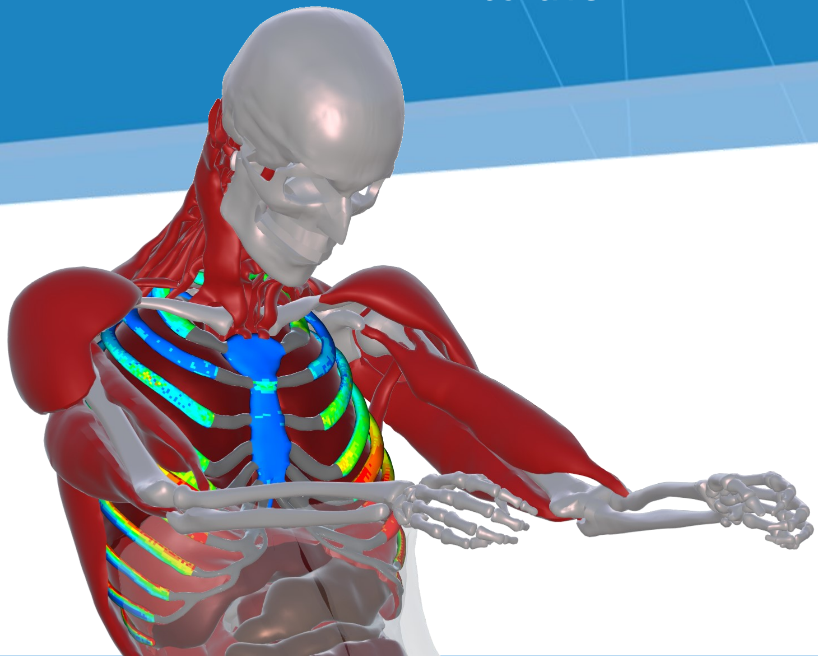

2022 GHBMC Users' Workshop

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Program

All Sessions held in the Galilee Conference Room

Breakfast, Breaks, Lunch and Reception held in the Atrium

07:45-08:45am Registration Open, Breakfast in the Atrium

08:45-09:00am Introduction (Scott Gayzik, Elemance)

09:00-09:20am State of the GHBMC (Daniel Kim, GHBMC)

09:20-10:20am Session I (Moderator– Skye Malcolm, Honda)

Is a Lower Crash Speed Needed for Restraint Design Optimization for an Urban Ridesharing Environment?

Jingwen Hu, Kyle Boyle, Andrew Leslie, Carol Flannagan, Chin-Hsu Lin, Raymond Kiefer
University of Michigan Transportation Research Institute (Ann Arbor, MI, USA), General Motors

**Public Transit Bus Occupant Response in Frontal Impacts Assessed Using Human Body Models*

Christopher Pastula, Kathy Tang, Jeffrey Barker, Duane Cronin
University of Waterloo (Waterloo, ON, Canada), Transport Canada Innovation Centre (Canada)

Capability of Small Female Human Surrogate Numerical Models to Assess Submarining Phenomenon in Frontal Impact Sled Test Environment

Anderson De Lima, Will Decker, Chin-Hsu Lin
General Motors (Detroit, MI, USA)

10:20-10:40am Break (Refreshments provided)

**Student Presentation– Eligible for the Student Award presented by Honda*

Program

All Sessions held in the Galilee Conference Room

Breakfast, Breaks, Lunch and Reception held in the Atrium

10:40am-12:00pm Session II (Moderator– James Gaewsky, Elemance)

**Preliminary Study of Topology Optimization for Modeling Subject-Specific Vertebral Trabecular Bone*

Austin M. Moore, Samantha M. Efobi, Ashley A. Weaver F. Scott Gayzik
Wake Forest University School of Medicine (Winston-Salem, NC, USA)

**Smooth Particle Hydrodynamics to Improve Post-Fracture Response Prediction of a Finite Element Functional Spinal Unit Model in Compression*

Sophia Ngan, Claire Rampersadh, Duane Cronin
University of Waterloo (Waterloo, ON, Canada)

Head Kinematics of the M50 and F05 Model for Volunteer 45-degree Oblique Impacts

Jeffrey Barker, Duane Cronin
University of Waterloo (Waterloo, ON, Canada)

**Updates on the GHBMC F05 Head Model Version 6.0 - Brain Strain Validation and Brain Injury Risk Function Development*

Ding Lyu, Shirin Phadke, Abhijeet Kumbhare, Liying Zhang
Wayne State University (Detroit, MI, USA)

12:00-1:20pm Lunch Break

**Student Presentation– Eligible for the Student Award presented by Honda*

Program

All Sessions held in the Galilee Conference Room

Breakfast, Breaks, Lunch and Reception held in the Atrium

1:20-2:40pm Session III (Moderator– Matthew Davis, Elemance)

Comparison of Far-Side Injury Risks as Predicted by Human Body Models to Estimations from Real-World Crashes in Similar Conditions

Berkan Guleyupoglu, Karan Devane, Fang-Chi Hsu, Bharath Koya, Ashley Weaver, Matthew Davis, F. Scott Gayzik
Elemance (Winston-Salem, NC, USA), Virginia Tech-Wake Forest University Center for Injury Biomechanics (Winston-Salem, NC, USA)

**Biofidelity Assessment of GHBMC M50-O in a Rear-Facing Seating Configuration in a High-Speed Frontal Impact*

Vikram Pradhan, Rakshit Ramachandra, Jason Stammen, Corey Kracht, Kevin Moorhouse, John Bolte, Yun-Seok Kang
The Ohio State University (Columbus, OH, USA), Transportation Research Center, Inc, NHTSA/VRTC, TS-Tech Americas INC

**Computational Assessment of the Effects of Active Musculature on Astronaut Body Kinematics and Injury Risk for Piloted Lunar Landings in a Standing Posture*

Mitesh Lalwala, Karan Devane, Bharath Koya, Scott Gayzik, Joel Stitzel, Ashley Weaver
Wake Forest University School of Medicine (Winston-Salem, NC, USA)

Development of Thoracic Injury Risk Functions for Human Body Models

Jason Forman, Shubham Kulkarni, Daniel Perez Rapela, Sayak Mukherjee, Bronislaw Gepner, Matthew Panzer, Jason Hallman
University of Virginia Center for Applied Biomechanics (Charlottesville, VA, USA), Toyota Motor North America R&D

2:40-3:00pm Break (Refreshments provided)

**Student Presentation– Eligible for the Student Award presented by Honda*

Program

All Sessions held in the Galilee Conference Room

Breakfast, Breaks, Lunch and Reception held in the Atrium

3:00-4:00 Session IV: GHBMC Tools (Moderator– Scott Gayzik, Elemance)

Human Body Model Positioning using Oasys PRIMER

Galal Mohamed– Ove Arup Systems - Oasys (Manchester, UK)

Biofidelic Positioning and Post-Processing of GHBMC Human Models with ANSA and META

Nikos Tzolas, Athanasios Lioras, Lambros Rorris– BETA CAE Systems SA (Thessaloniki, Greece), BETA CAE Systems International AG

Metriks: The Human Body Model Post-Processor

James Gaewsky– Elemance, LLC (Winston-Salem, NC, USA)

4:00-4:10pm Student Award Presentation (Presented by Honda)

4:10-4:15pm Closing Remarks (Matthew Davis, Elemance)

4:15-6:15pm Reception and Hors d’oeuvres

Session I

Is a lower crash speed needed for restraint design optimization for an urban ridesharing environment?

Jingwen Hu[1], Kyle Boyle[1], Andrew Leslie[1], Carol Flannagan[1], Chin-Hsu Lin[2], and Raymond Kiefer[2]
[1] University of Michigan Transportation Research Institute
[2] General Motors

Introduction: Because rideshare is generally conducted in urban and relatively lower speed environments, automated vehicles that operate in a ridesharing capacity may experience crashes with lower crash speeds than national crash datasets would suggest. Furthermore, rideshare is likely to increase the occupancy rates for both front- and rear-seated passengers, who do not need to drive, and passengers, especially rear-seat passengers, are not well represented in vehicle crash test programs for safety designs. Therefore, the goal of this study was to investigate how the injury distribution on body regions would be changed if restraint systems were optimized for front- and rear- seated passengers under a lower frontal crash speed than those defined in the current regulated or consumer information frontal crash tests.

Materials and Methods: In this study, we first conducted restraint design optimizations for front- and rear-seat passengers at a high-speed (35 mph) and a low-speed (20 mph) frontal crash using two Finite Element (FE) human models (GHBMC-M50-OS and GHBMC-F05-OS). The two sets of optimal designs (high-speed vs. low-speed), as well as the baseline restraint model, were further evaluated in a wide range (n=55) of frontal crash conditions for both the front passenger seat and rear seat using three human models (GHBMC-M50-OS, GHBM-F05-OS, and a morphed midsize female model).

Results and Discussion: It was found that restraint optimizations at lower speed can generally provide better protection to occupants in crash environments associated with urban ridesharing, as compared to optimizations which meet current regulated or consumer information frontal crash tests. However, the small female front passenger did not benefit from restraint optimization at lower speed due to the optimization compromise between the midsize male and small female occupant, both seated in mid-track position, as well as due to less airbag engagement for the small female occupants.

Conclusions: This simulation study demonstrated the need to reconsider the crash speed for restraint design optimization for an urban ridesharing environment, in which the majority of the crashes occur at lower speeds. However, this initial study is limited by using only one vehicle model, a portion of the simulations terminated with errors, and the limited range of size and shape of occupant models. More investigations are desired to further prove and examine the robustness of the reported findings from this study.

Acknowledgements (Optional): This study was funded by General Motors.

Public Transit Bus Occupant Response in Frontal Impacts Assessed Using Human Body Models

Christopher Pastula[1], Kathy Tang[1,2], Jeffrey Barker[1], Duane Cronin[1]

1. University of Waterloo, Waterloo, Ontario, Canada
2. Transport Canada, Innovation Centre, Canada

Introduction: Public transit buses do not currently implement crashworthiness standards for the protection of passengers in North America. Passengers are unrestrained on buses, resulting in a risk of impacting surrounding interior structures such as metal handrails in the event of a crash. Transport Canada has recently conducted full-scale and deceleration sled frontal impact experiments to investigate transit bus passenger injury mechanisms with the use of Hybrid III (HIII) ATDs [1]. The aim of the current study was to develop a model of the TC sled buck, validate it using the responses of HIII ATD models, and incorporate the GHBMC HBMs (M50 and F05) in the test buck model for injury assessment.

Materials and Methods: A finite element model of the sled buck used by TC was modeled and validated for the responses of HIII 50th and 5th percentile ATDs. The validation was comprised of a qualitative assessment comparing the highspeed video and HIII model motion, followed by a quantitative assessment using CORA software with the kinematics from the head, neck, chest, and femurs. The GHBMC M50 and F05 V5.1 models were seated in the test buck with a 6.5g frontal pulse. Injury was assessed using injury metrics (HIC_{15}, N_{ij}, Chest compression, femur loads, etc.) for the HIIIs and HBMs [2], followed by a tissue level injury assessment with the HBMs. Fracture thresholds obtained from the literature were used to assess focal injury to the larynx and mandible resulting from the handrail impact [3,4].

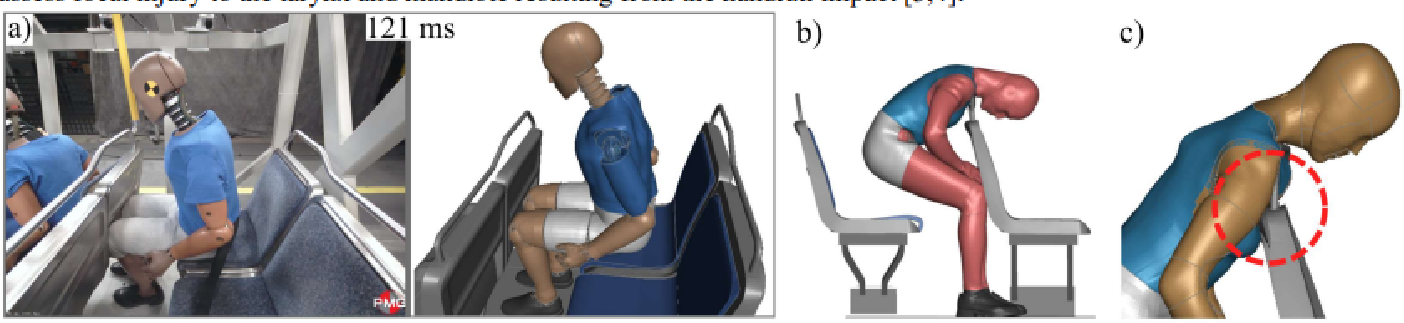


Figure 1. a) Comparison of highspeed video from experiments with HIII model for validation; b) M50 HBM occupant response (6.5g frontal, 252 ms; c) F05 HBM impacts the top of the forward seat frame and predicts a sternum fracture as a result (6.5g pulse, 222 ms)

Results and Discussion: The general occupant response from the experiments showed that the HIIIs slid forward off the seat and impacted the forward handrail on the anterior neck for the 50th male and the lower face for the 5th female. The validation of the HIII responses showed good biofidelity using the highspeed video and CORA analysis (avg. 0.71). The M50 and F05 HBMs seated in the test buck model both impacted the forward handrail on the anterior neck. A crushing injury to the larynx cartilages (AIS-5), mandible injury (AIS-3), and upper neck injury (AIS-3) were likely to occur based off injury metrics from HIII and HBM models. The F05 HBM also predicted a sternum fracture (AIS-3) from focal loading to the thorax from the top of the forward seat frame.

Conclusions: In conclusion, validation of a test buck model showed good biofidelity for the responses of the 50th and 5th percentile HIII ATDs. The injury assessment with the models showed a potential for focal injury to the larynx and face due to impact with the forward handrail, demonstrating a potential risk of injury from placement of metal structures in the bus.

References:

[1] Tylko, S., Tang, K., Bussières, A., Duval, M., Giguère, F., (2020). Interim Report Transit Bus Research, Transport Canada

[2] Eppinger, R., Sun, E., Bandak, F., Haffner, M., Khaewpong, N., Maltese, M., Kuppa, S., Nguyen, T., Tankhounts, E., Tannous, R., Zhang, A., Saul, R., (1999), Development of Improved Injury Criteria for the Assessment of Advanced Automotive Restraint Systems – II, National Highway Traffic Safety Administration

[3] Melvin, J., Snyder, R., Travis, L., and Olson, N. (1973), Response of Human Larynx to Blunt Loading, SAE Technical Paper 730967, https://doi.org/10.4271/730967.

[4] Daniel, R., Weisenbach, C., McGovern, S., Rooks, T., Chancey, V., Brozoski, F. (2021). Fracture Injury Risk of the Restrained Mandible to Anterior-Posterior Blunt Impacts, Journal of Biomechanical Engineering (vol. 143 issue 4), doi: 10.1115/1.4050122

Acknowledgements: The authors would like to express their appreciation to the Global Human Body Models Consortium, the Natural Sciences and Engineering Research Council of Canada, Stellantis Canada, GM Canada, and Honda Development and Manufacturing of America for financial support of this research, Compute Canada for providing the necessary computing resources, and Transport Canada for providing the experimental data.

Capability of small female human surrogate numerical models to assess submarining phenomenon in frontal impact sled test environment

Anderson De Lima[1], Will Decker[1], Chin-Hsu Lin[1]
1. General Motors

Introduction: Interest in innovative vehicle interior designs is increasing rapidly. Some concepts may allow occupants to sit in a wide variety of orientations and postures. Increased allowable seatback recline angle, while the vehicle is in motion, is one such posture that challenges how restraint systems couple with occupants. Increased seatback recline angle may put occupants at risk to submarining, which occurs when the lap belt slides above the iliac crest and intrudes into the abdominal region.

Materials and Methods: In the current study, the authors assess the capability of Global Human Body Model Consortium (GHBMC) and Anthropometric Test Device (ATD) small female human surrogate numerical models to predict the submarining phenomenon in three different configurations using a semi-rigid seat. These configurations are based on frontal impact sled tests performed with post-mortem human subjects (PMHS) by Trosseille et al., 2018. The first configuration was designed to avoid submarining. The second and third were designed to induce submarining by changing the lower anchorages points, reducing the stiffness of the seat and anti-submarine ramp, and introducing 40 mm of slack to both strands of the lap belt. Configuration 2 also included moving the pelvis forward by 50 mm. The computational simulations were conducted with the Humanetics Harmonized H-III 5F v2.0, GHBMC detailed occupant (F05-O v5.1 age 70YO) and simplified occupant (F05-OS v2.2) models. The numerical and experimental time history results were evaluated against multiple criteria (e.g., submarining time, seat pan and anti-submarining ramp forces and rotation, seatbelt forces, pelvis excursion and rotation, pelvis and chest accelerations, h-point displacement etc.). Comparisons to the H-III 5F physical tests were based on data from Trosseille (2022).

Results and Discussion: Computational results were compared with available PMHS and ATD tests. Time of submarining correlations are shown in Table 1. For Configuration 1, submarining did not occur in the physical tests or the ATD and GHBMC simulations. For Configurations 2 and 3, the GHBMC F05-OS showed submarining tendency comparable to PMHS, it submarined about 10ms earlier than the earliest PHMS. The GHBMC F05-O 70YO simulation results showed submarining at about the same time as the earliest PMHS. The H-III 5F numerical model also indicated submarining for Configuration 2. Timing was in between the PMHS and the H-III 5F physical test with a slightly better correlation to the ATD tests. The H-III 5F numerical model did not submarine in Configuration 3. The H-III 5F physical test showed submarining very late and only for the right iliac.

Table 1. Submarining timing.

Configuration	PMHS	Submarining time (ms)		H-III 5F Physical Test		H-III 5F v2.0 Simulation		GHBMC F05-OS v2.2		GHBMC F05-O v5.1 70YO	
		Left	Right	Left	Right	Left	Right	Left	Right	Left	Right
Conf. 1	713	No	No	No	No	No	No	No	No	No	No
	714										
	715										
	716										
Conf. 2	721	55	55	64.15	64.50	60.00	62.50	45	45	52.5	52.5
	722	55	54								
Conf. 3	723	73	75	No	107	No	No	60	55	67.5	65
	724	65	79								
	725	69									

Conclusions: The computational model results match the experimental tests reasonably well for the tendency of submarining. GHBMC F05-O 70YO is showing better overall correlation with PMHS data in terms of kinematics than the GHBMC F05-OS and the H-III 5F. Given that the average PMHS age was 75.5 years, the correlation performance of the GHBMC F05-O 70YO model appears to be directionally correct.

Acknowledgements: The team would like to thank SUB-Bio members: LAB PSA Renault, Toyota, Faurecia and CEESAR, for providing the finite elements model of the sled test and the physical test results.

References: [1] Trosseille X., Petit P., Uriot J., Potier P., Baudrit P., Richard O., Compigne S., Masuda M., Douard R. (2018) Reference PMHS Sled Tests to Assess Submarining of the Small Female. Stapp Car Crash Journal 62:93-118. [2] GHBMC F05-OS Version 2.2 User Manual, 2019, Global Human Body Models Consortium.[3] GHBMC F05-O Version 5.1, 2020, Global Human Body Models Consortium.[4] Trosseille, X., (2022) personal communication from April 04, 2022.

Session II

2022 GHBMC Users' Workshop
August 16, 2022
The Inn at St John's, Plymouth, Michigan

Preliminary Study of Topology Optimization for Modeling Subject-Specific Vertebral Trabecular Bone

Austin Moore[1], Samantha Efobi[1], Ashley Weaver[1], F. Scott Gayzik[1,2]

1. Wake Forest University School of Medicine, Winston-Salem, NC
2. Elemance, Winston-Salem, NC

Introduction: Current analyses of fracture risk involve subject-specific finite element models (FEM) that incorporate bone morphology, volumetric bone mineral density (vBMD), and cortical thickness estimates from quantitative computed tomography (qCT) scans. However, vertebral trabecular bone is modeled as a homogenous solid despite being a significant and independent factor in fracture risk assessment. We develop a different approach for representing vertebral trabeculae, called the Computed Trabecular Network (CTN), inspired by Wolff's Law.

Materials and Methods: Computed tomography images were acquired of the lumbar spine in 4 cadavers. Lumbar vertebrae were removed and the endplates potted in a quick-setting polyurethane. Each specimen was compressed axially by a servohydraulic uniaxial loading system (MTS Landmark, Eden Prairie, MN) at 0.15mm/s until failure. The force-displacement data from each specimen will be compared to a matched subject-specific finite element model under the same loading conditions. Vertebral morphology is estimated from the images, and lumbar vertebrae in the GHBMC 50th-percentile male occupant (M50-O) v6.0 with aged spine material are morphed to match the cadaveric vertebrae.
To simulate the daily loading that drives physiologic bone remodeling, we consider the compressive force on L1 from weight and the tensile force from muscles that act on L1. To model compression, we apply a force of 490N to the superior endplate[1]. Using a lumbar spine musculoskeletal model in OpenSim 4.1, we determine the tensile force of all muscles acting on L1 to maintain standing posture[2, 3]. We import this FEM to Optistruct (Altair Engineering, Troy, MI) and use topology optimization to iteratively determine the optimal distribution of trabecular elements in the vertebral body to minimize global compliance, thereby maximizing stiffness of the model. We impose a volume fraction limit of 15%, derived from the average trabecular bone volume fraction of vertebrae[4].

Results and Discussion: Compared to compression simulations using the baseline model, morphed vertebrae more closely matched the experimental force-displacement trace. The subject-specific CTN is expected to be an even more significant improvement. Preliminary CTN using baseline vertebra (**Figure 1**) have converged to a feasible solution that meets all boundary criteria and minimizes stress during the load.

Conclusions: We introduced a vertebral trabecular bone model inspired by Wolff's Law. Future direction includes further validation by comparing experimental testing of cadaveric vertebrae to compression simulations of the morphed CTN.

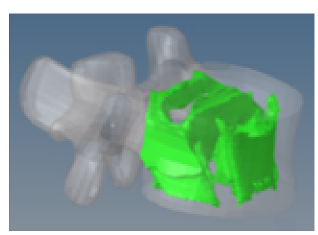


Figure 1: L1 CTN (green) with transparent cortex (gray)

Acknowledgements: Research reported in this abstract was supported by the National Institute on Aging of the National Institutes of Health under award number **F30AG063444**. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

References: [1] Han KS. Med Eng Phys. 2013;35(7):969-77. [2] Raabe ME. J Biomech. 2016;49(7):1238-43. [3] Delp SL. IEEE Trans Biomed Eng. 2007;54(11):1940-50. [4] Hazrati-Marangalou J. Osteoporos Int. 2014;25(4):1285-96.

2022 GHBMC Users' Workshop
August 16, 2022
The Inn at St John's, Plymouth, Michigan

Smooth particle hydrodynamics to improve post-fracture response prediction of a finite element functional spinal unit model in compression

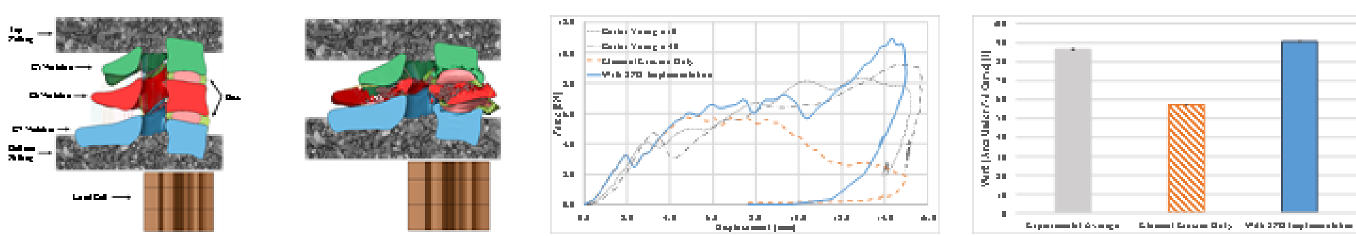
Sophia Ngan[1], Claire Rampersadh[1], Duane S Cronin[1]

1. Department of Mechanical and Mechatronics Engineering, University of Waterloo, Canada

Introduction: Detailed finite element human body models (HBMs) are developed to assess injury risk; however, hard tissue fracture prediction presents challenges for many contemporary models. When vertebral fracture is modelled with a strain-based element erosion criterion, material volume is lost, reducing structural support and limiting the potential to simulate spinal canal occlusion under compression. To enhance the fracture and post-fracture response of HBM vertebrae, smooth particle hydrodynamics (SPH) was combined with element erosion.

Materials and Methods: A functional spinal unit (FSU) model of the C5 to C7 vertebrae from the GHBMC detailed occupant model (M50-O V6.0) with an anisotropic trabecular bone material model was investigated to model compression fracture (Figure 1) [1]. The FSU was loaded under centric compression based on the experimental work done by Carter [2]. A pre-load of 40 N was first applied, followed by a displacement of 15 mm. Failure of the C6 trabecular bone elements was modelled with strain-based element erosion at a minimum principal strain of -0.90 and a maximum principal strain of 0.092. Upon erosion, the solid Lagrangian elements were transformed to SPH elements. The SPH elements were assigned elastic material properties with a Young's modulus of 0.442 GPa, corresponding to the stiffness of the trabecular bone.

Results and Discussion: During compression, the experimental FSUs showed a relatively linear increase in force up to the initiation of fracture (Figure 1), followed by an increase in force at a lower slope and a steep unloading response. The current GHBMC M50-O model, using element erosion only, predicted a decrease in the post-fracture force-displacement response. However, when the eroded elements were transformed to SPH elements, the overall force-displacement response increased throughout loading, in agreement with the experimental data. During loading, the average work (area under the curve) for the experimental tests was 86.4 J. In comparison, the model with only element erosion showed a lower work of 57.2 J due to material loss. The model with the SPH implementation had a total work of 90.5 J, in good agreement with the experiments, owing to the continued load support from the SPH elements. The addition of SPH increased compute time by 65%. The SPH elements also demonstrated greater intrusion in the spinal canal, which will be investigated in future studies.



(a) (b) (c) (d)

Figure 1. Sagittal cross-sectional view of the FSU (a) with labels, and (b) at maximum displacement. (c) The force-displacement responses, and (d) the areas under the force-displacement curves up to the maximum displacement.

Conclusions: The addition of SPH improved the post-fracture force-displacement response of the model in compression to be in better agreement with the response from the experimental work from Carter.

Acknowledgements: The authors would like to express their appreciation to the Global Human Body Models Consortium, the Natural Sciences and Engineering Research Council of Canada, Stellantis Canada, GM Canada, and Honda Development and Manufacturing of America for financial support of this research, and Compute Canada for providing the necessary computing resources.

References: [1] F. Khor, Computational Modeling of Hard Tissue Response and Fracture in the Lower Cervical Spine under Compression Including Age Effects, Waterloo, Ontario: University of Waterloo, 2018. [2] J. W. Carter, Compressive Cervical Spine Injury: The Effect of Injury Mechanism on Structural Injury, Seattle, Washington: University of Washington, 2002.

Head kinematics of the M50 and F05 v6-0 model for volunteer 45-degree oblique impacts

Jeff Barker, Duane Cronin. University of Waterloo

Introduction: HBMs have primarily been validated for orthogonal loading directions by comparing model and experimental head kinematics[1]. With the growing autonomous driving vehicle fleet, oblique impacts may become more common[2], and therefore HBMs should be validated for such loading scenarios. HBMs have been validated in the oblique loading direction for PMHS testing[3], but not against volunteer testing where active muscle is important to response. The Naval Biodynamics Laboratory (NBDL) conducted volunteer frontal and lateral impacts, and the data from those experiments have been used extensively to validate the GHBMC models. NBDL also conducted oblique impact tests with five sled pulse severities (4g through 11g), but that data has never been used for HBM validation before. The goal of this study is to validate the M50 and F05 v6-0 models with the oblique data from NBDL.

Materials and Methods: The NBDL kinematic test data was download from the NHTSA biomechanics database and cross referenced with an NBDL report[4] for anthropometric information. The test data included sled, T1, and head CG instrumentation data. The individual tests were divided into five groups based on the sled acceleration pulse, and the kinematics measures were averaged for each group. No time scaling or warping was used to average the data. The models used in this study were the GHBMC M50-O and F05-O v6-0 models. The head and neck models were extracted from the full body occupant models. Kinematic BC was applied to the T1, and the resultant head model kinematics were compared (Figure 1) with the head kinematic data (translation and rotation, and displacement and acceleration). The motion applied to T1 in the X-axis translation and all three axes of rotation. The model response was objectively compared using CORA, and the three kinematic components were weighted based on the total area under the curve of each experimental component trace.

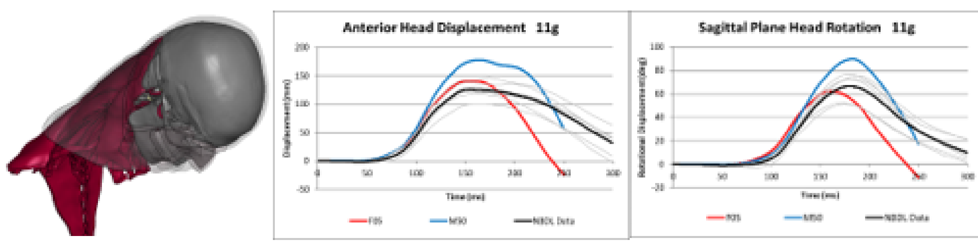


Figure 1. M50 11g model (left) response in anterior (X-axis) displacement and sagittal plane (Y-axis) rotation

Results and Discussion: The CORA rating for the M50 and F05 model were 0.69 and 0.63 respectively. CORA ratings with displacement were higher than with acceleration, and translation kinematics generated higher ratings than rotational kinematics. Across the five severities, the CORA ratings indicated that model response was slightly more biofidelic for the lower severity cases. In general, the M50 model was more compliant than the data. The primary motion axes were anterior translation and sagittal plane rotation (Figure 1), and in those axes, the peak model response was higher than the experimental data.

Conclusions: The M50 and F05 models, at the head and neck level, were assessed against a new dataset that had not been used to validate or calibrate HBMs. The model response was more compliant than the data, but generally was within one standard deviation corridors with respect to the average response. Overall, the models showed moderate to good correlation in a new load case, and it bodes well for their usage in assessing vehicle safety in autonomous vehicles.

Acknowledgements:
The authors would like to express their appreciation to the Global Human Body Models Consortium, the Natural Sciences and Engineering Research Council of Canada, Stellantis Canada, GM Canada, and Honda Development and Manufacturing of America for financial support of this research, and Compute Canada for providing the necessary computing resources.

References: 1. Barker 2021. J Biomech Eng. doi: 10.1115/1.4047866
2. Koppel 2019. Traff Inj Prev. doi: 10.1080/15389588.2019.1625336
3. Poulard 2020. Report No. DOT HS 812 905
4. Spenny 1987. Report No. DOT HS 807 159

Updates on the GHBMC F05 Head Model Version 6.0 - Brain Strain Validation and Brain Injury Risk Function Development

Ding Lyu, Shirin Phadke, Abhijeet Kumbhare, Liying Zhang
Biomedical Engineering, Wayne State University

Introduction: Previously we reported the update of the Global Human Body Modeling Consortium (GHBMC) 50th percentile male (M50) head model by incorporating fiber directions and anisotropic properties to the brain. The current and all prior versions of the GHBMC 5th percentile female (F05) head model defined the brain tissue as an isotropic material. This study reports the major updates of the F05 head model from v5.0 to v6.0 to capture directional dependent responses in the white matter structures. The F05 v6.0 was also subjected to brain strain validation to improve the biofidelity which has not been done in all prior versions. New risk functions were developed for the Crash Induced Injury (CII) to improved predictive capability of the F05 head model in predicting various head injuries.

Materials and Methods: The brain was defined with a new anisotropic viscoelastic material model by using *MAT_SOFT_TISSUE and *MAT_ADD_INELASTICITY available in LS-DYNA R12.0. The direction of the neuronal fiber architecture was defined via MAT Coordinates for various white matter structures. F05 v6.0 head model was subjected to extensive validations of kinematic, kinetic, and strain responses against data measured from over 30 postmortem human subject (PMHS) experiments conducted in a variety of impact conditions. A total of 45 PMHS and accident reconstruction data were then simulated and tissue level response parameters from the FE model were analyzed with Weibull, LogNormal, Loglogistic parametrical survival model and logistic regression model to develop risk functions for various injuries in the face, skull, and brain.

Results and Discussion: *Model validation* – The brain strain history simulated by the F05 v6.0 showed similar trend and magnitude to the experiment data after the brain properties were updated from the previous model. The average CORA from 7 cases was 0.59. The intracranial pressure and ventricular pressures from the model also had good correlation with the PMHS results in frontal impact. The skull F-D and stiffness predicted in the frontal, temporal, parietal and occipital bones were validated against skull impact from various locations. The facial force-deflection (F-D) response in the nasal, zygomatic, and maxilla regions were also validated. *CII development* – The CII for cerebral contusion was developed based on ICP parameters from15 PMHS tests reported with and without contusion. The logistic regression model had the area under receiving operating characteristic curve (AUC) of 0.82 which is considered as excellent. For acute subdural hematoma CII, the strain experienced by the subdural bridging vein (BV) was assessed from a total of 10 PMHS cases and the injury risk function based on logistic regression model was established with an AUC of 0.8. The BV strain level for a 50% risk of rupture was consistent with material failure data reported. The product of strain and strain rate in the white matter was assessed to be the better CII than strain alone for differentiating diffuse brain injury of AIS 4+ from AIS 2.

Conclusions: The new transversely isotropic material model developed and implemented in the F05 v6.0 offered improved predictability for simulating directional properties of the white matter and associated injury severity due to different impact directions. The F05 v6.0 is the first version of the GHBMC female head model that has validated against brain strain responses to ensure the biofidelity of strain-induced brain injury prediction. The F05 v6.0 head model is equipped with various CII functions capable of assessing the risk and occurrence of various head injuries: fracture to the face and the skull of various regions, cerebral contusion, acute subdural hematomas, and diffuse brain injury. Seven out of 9 CIIs developed are ranked Capability Level 0 (reasonability predictive) and 2 CIIs are Ranked Capability Level 2.

Acknowledgements (Optional): This study was supported by the Global Human Body Model Consortium (GHBMC), LLC.

Session III

Comparison of Far-Side Injury Risks as Predicted by Human Body Models to Estimations from Real-World Crashes in Similar Conditions

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Introduction: Far side impacts are a specific classification of side impacts in which the occupant is positioned on the non-struck side of the vehicle. Far side impacts have the second highest risk of injury of all crash modes [1]. In 2010, a report was released by the Monash University Accident Research Center which demonstrated that from 1988 to 2000 increases in frontal collision occupant safety reduced the proportion of frontal collision fatalities however, side impact related fatalities increased. While a systematic review of far-side studies in the literature was conducted, as well as field-data based risk curves for far-side injury were developed [2], a gap remains in determining if human body models (HBMs) capture the trends associated with these curves.

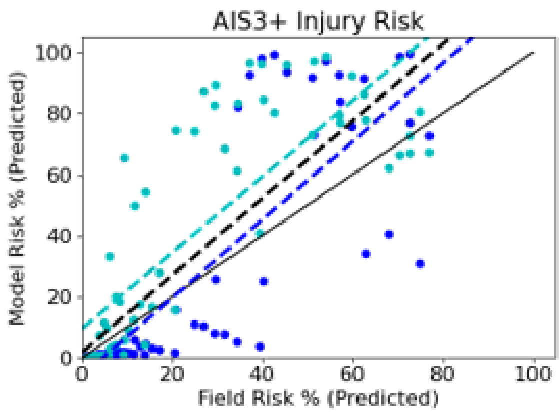

Figure 1 Cross plot of AIS 3+ risk of injury in far-side crashes as predicted by the M50-OS (blue), and F05-OS (cyan) with field estimations of risk. Points above line of equivalence (solid black) mean higher predictions by HBMs and point below are under predictions by HBMs. Dashed lines are linear regressions for M50-OS (blue), F05-OS (cyan) and overall HBM (black) data.

Materials and Methods: The Global Human Body Models Consortium (GHBMC) average male (M50) and small female (F05) simplified models (-OS) were used in this study. The models were gravity settled over 150 msec and subsequently belted into a simplified vehicle model (SVM). Boundary conditions were derived from full vehicle impacts across a range of 7 PDOFs (50-90°) and 9 lateral ΔV's (10-50 kph; 63 simulations per model). Biomechanical risk curves and a field data based risk curve were used for injury risk prediction comparisons.

Results and Discussion: Overall risk of AIS 3+ injury risk was strongly correlated to the field data-based risk curves (Figure 1). HBMs were able to capture approximately 63.4% of the total variance. When the HBM data is split by model, the F05-OS demonstrates generally higher risks in far side impacts relative to the M50-OS suggesting smaller anthropometry increases risk in far-side crashes. The M50-OS, while generally under predicting risk in these cases, is more evenly spread across the line of equivalence. The risks predicted by the HBMs were found to be statistically different from each other ($p<0.05$). Belt slippage was present in all simulations and may be a driver of increased risk predictions.

Conclusions: The M50-OS and F05-OS capture a combined 63.4% of the total variance. The M50-OS tends to predict more evenly across the line of equivalence while the F05-OS tends to over predict risk in far side crashes.

Acknowledgements: This study was funded by the United States Council for Automotive Research (USCAR) under grant ID: 21-2262-USC

References: [1] Augenstein, J., et al., *Characteristics of crashes that increase the risk of serious injuries.* Ann Adv Automot Med, 2003. p. 561-76.
[2] Hostetler, Zachary S., et al. *Injury risk curves in far-side lateral motor vehicle crashes by AIS level, body region and injury code.* Traffic injury prevention, 2020, S112-S117.

Biofidelity Assessment of GHBMC M50-O in a Rear-Facing Seating Configuration in a High-Speed Frontal Impact

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Introduction: Future vehicles equipped with automated driving systems (ADS) may include a rear-facing (RF) seating configuration for front-row occupants [1]. To evaluate seats and restraint systems necessary for protecting RF occupants in a frontal crash, safety tools such as anthropomorphic test devices (ATDs) and finite-element (FE) human body models (HBMs) should replicate human-like characteristics under such conditions. Recently, a series of high-speed (56km/h) RF frontal impact sled tests were conducted to investigate biomechanical responses and injuries of 50th percentile male post-mortem human subjects (PMHS) using all-belts-to-seat (ABTS) seats [2]. PMHS response corridors were generated and used to assess biofidelity of the THOR-50M ATD [3]. However, biofidelity of HBMs has not been evaluated under such conditions yet. As an initial step, the objective of this study was to assess the biofidelity of the Global Human Body Models Consortium (GHBMC) 50th percentile male detailed occupant model (M50-O v6.0) seated in an ABTS seat with a rigidized seatback (standard 25-degree recline) in a 56 km/h RF frontal impact.

Materials and Methods: The experimental boundary conditions from the PMHS tests were replicated in the computational FE environment. The performance of the ABTS seat FE model obtained from the original equipment manufacturer (OEM) was validated via simulations using a Hybrid III FE model. The seat model was modified by optimizing the low-density foam (MAT 57) material model used in the seatback and head-restraint (HR) using a polymeric foam modeling approach [4]. The GHBMC M50-O was positioned on the modified seat utilizing prescribed final geometry functions, a belt pulling method [5] and gravity settling. The spinal curvature and key bony landmarks of the GHBMC were set within one standard deviation (SD) of the PMHS mean for corresponding parameters. GHBMC kinematics were measured at the anatomical locations consistent with the PMHS. Biofidelity was evaluated using the NHTSA Biofidelity Ranking System (BRS) [3], where a BRS score under 2 indicates that the GHBMC response is within two SD of PMHS mean response, suggesting good biofidelity.

Results and Discussion: The GHBMC M50-O received BRS scores of 1.59 for mean occupant response and 1.58 for seat loading. Spine straightening behavior of the GHBMC quantified using y-angular velocity was similar to PMHS, with thoracic spine and pelvis receiving BRS scores of 1.56 and 0.86, respectively. The GHBMC displayed similar occupant ramping along the seatback as the PMHS, with a BRS score of 1.63 for pelvis z-excursion. However, BRS scores of 2.19 and 2.27 were observed in head and T1 x-excursions, respectively, due to dissimilar interaction with the HR. Although chest compression (30%) of the GHBMC was consistent with PMHS, the relative upward motion of abdominal contents and subsequent chest expansion were not observed in the GHBMC.

Conclusions: This study evaluated the biofidelity of the GHBMC M50-O v6.0 in a 56km/h RF frontal-impact scenario. Most results provide some confidence in using the GHBMC under high-speed RF conditions using the ABTS seat. However, updates to the GHBMC towards improved head/neck kinematics and mobility of abdominal organs should be considered to replicate PMHS characteristics more closely.

References: [1] Jorlöv, Sofia, Katarina Bohman, and Annika Larsson. "Seating positions and activities in highly automated cars– a qualitative study of future automated driving scenarios." International Research Conference on the Biomechanics of Impact. 2017. [2] Kang, Yun-Seok, et al. "Biomechanical responses and injury assessment of post mortem human subjects in various rear-facing seating configurations." Stapp car crash journal 64 (2020): 155-212. [3] Hagedorn, Alena et al. "Biofidelity Evaluation of THOR-50M in Rear-Facing Seating Configurations Using an Updated Biofidelity Ranking System." SAE Int. J. Trans. Safety 10(2):2022, doi:10.4271/09-10-02-0013. [4] Alzoubi, M. F., S. Al-Hallaj, and M. Abu-Ayyad. "Modeling of compression curves of flexible polyurethane foam with variable density, chemical formulations and strain rates." Journal of Solid Mechanics 6.1 (2014): 82-97. [5] Poulard, David, et al. "Development of a computational framework to adjust the pre-impact spine posture of a whole-body model based on cadaver tests data." Journal of biomechanics 48.4 (2015): 636-643.

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Computational Assessment of the Effects of Active Musculature on Astronaut Body Kinematics and Injury Risk for Piloted Lunar Landings in a Standing Posture

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Introduction: Since the Moon's gravity is one-sixth of Earth's, as in the past there is a possibility astronauts may pilot future lunar landers in a standing versus recumbent posture. Previously, we assessed standing astronaut kinematics and injury risk for piloted lunar landing using the GHBMC simplified pedestrian model M50-PS. This work showed the absence of active musculature may influence predicted kinematics (e.g. knee-buckling) and injury risk during lunar landing events. The current study aims to overcome this limitation by developing an active muscle human body model (HBM) in a standing posture, and assess the effects of active muscles on astronaut body kinematics and injury risk.

Materials and Methods: A simplified active muscle HBM in a standing posture, M50-PS+Active, was developed. This model incorporated 116 major skeletal muscles as one-dimensional beam elements using a Hill-type muscle material model with a closed-loop muscle activation strategy, in the GHBMC M50-PS model (v1.5.2) (Fig. 1A). The model was validated standing in earth gravity and with volunteer step-down tests to assess its biofidelity. The lunar landing conditions were simulated by applying a half-sinusoidal acceleration pulse with varied peak accelerations and rise time to the ground in the vertical and 10º offsets in the lateral and anterior-posterior directions (Fig. 1B). The effects of active muscles on astronaut response were characterized by comparing the M50-PS+Active model response with the M50-PS model across 30 simulations (10 directions×3 pulses).

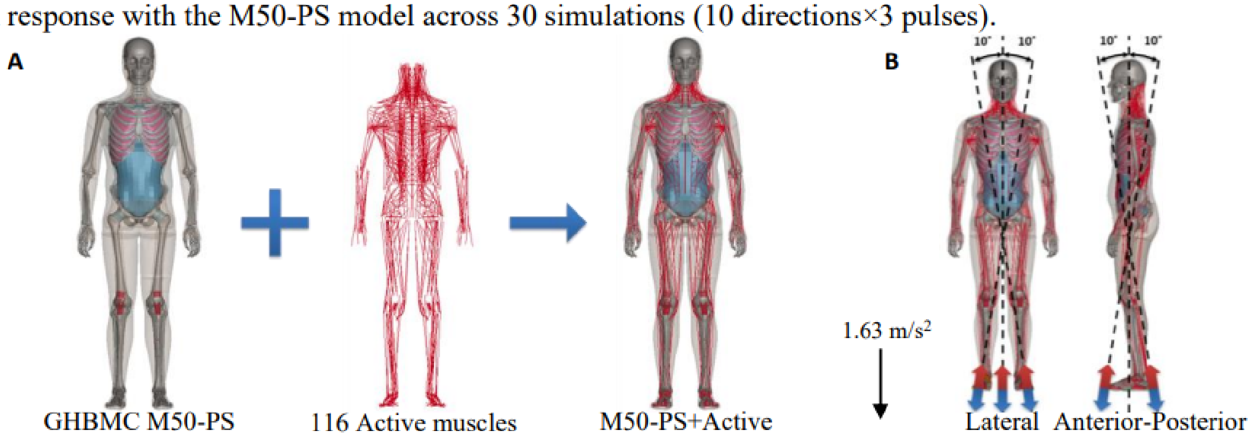

Figure 1 – A) GHBMC M50-PS+Active model development B) Simulation setup for lunar landing

Results and Discussion: The active model showed improved postural stability in the gravity standing test, and good biofidelity with volunteer response in step-down tests with an overall CORA score of 0.80 vs. 0.64 in the passive model. The active muscle prevented knee-buckling, lowering the tibia injury risk in the active vs. passive model (revised tibia index: 0.02–0.40 vs 0.01–0.58), below NASA's tolerance limit (0.43). Head displacement was higher in the active vs. passive model (11.6 vs. 9.0 cm forward, 6.3 vs. 7.0 cm backward, 7.9 vs. 7.3 cm downward, 3.7 vs. 2.4 cm lateral), whereas arm movement was lower (23 vs. 35 cm backward, 12 vs. 20 cm downward).

Conclusions: Overall simulations suggested that the passive model may overpredict injury risk in astronauts for spaceflight loading conditions, which can be improved using the model with active musculature.

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Development of thoracic injury risk functions for human body models

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Introduction: Human body models (HBMs) provide opportunities for virtual assessment that complement physical evaluations. Like dummies, however, human body models need a means to translate quantitative measures into predicted injury risk. This study describes a method to develop thoracic injury risk functions tuned for specific human body models, illustrated using THUMS V4.1 and GHBMC M50-O V6.0.

Materials and Methods: For this study, we took an approach common to developing injury risk functions for other surrogates. Specifically, we performed simulations targeting test conditions used in past tests with postmortem human surrogates (PMHS). We then performed regression and optimization to relate thoracic measures from the human body models to injuries observed in the matched PMHS tests. Simulations were performed in nine frontal-impact loading modes derived from the literature, including hub impact tests, bar impact tests, and table-top tests with belt loading. The model input conditions were adjusted based on the input conditions used for each specific PMHS test, resulting in a simulation with each HBM for each individual PMHS test. In all, approximately 170 individual simulations were performed with each HBM, distributed across the nine loading modes. Various deflection and strain-based outputs from these simulations were examined to determine which measures (or combination of measures) best predicted the AIS3+ rib fracture injuries observed in the PMHS tests.

Results and Discussion: When examining injury prediction using local rib strain, our results found that the local failure criteria (cortical bone ultimate strain) should be adjusted based on the rib strains observed in each specific human body model to provide appropriate predictive ability across models. As a result, the local strain-based injury risk function tuned for the GHBMC model differed from that tuned for THUMS. Both differed (to different degrees) from rib ultimate strain distributions observed in the literature, derived from cortical bone material property tests.

Conclusions: Like dummies, each human body model composition is different. Therefore, it may not be appropriate for injury risk functions to be the same across all human body models. Instead, the relationship between internal measures experienced by the models and the risk of injury in a matched condition with a human is affected by the specific construction, biofidelity, and response of each model. This study provides a framework to tune injury risk functions for application to specific human body models. This framework may provide a means to arrive at comparable thoracic injury prediction across various human body models, despite their differences.

Session IV

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Biofidelic positioning and post-processing of GHBMC Human Models with ANSA and META

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Introduction:
HBMs have become a much-needed tool for safety simulations in the automotive industry. Simulations for Out-of-position cases and for other vulnerable road users, such as, pedestrians and cyclists are increasingly needed, and HBMs are ideal to cover the requirements of such analyses. Nevertheless positioning, pre-processing and post-processing of such models on a level suitable for industrial use is not as straight-forward and poses challenges.

Materials and Methods:
The developments during the last two years on the ANSA pre-processor have been based on the technologies of an advanced integrated MBD solver and the morphing algorithms used in parallel. All the meta-data needed for the various GHBMC models are produced by BETA CAE Systems and are distributed along with the models. Regarding the post-processing of GHBMs, tools that automate the extraction of the results and the calculation of injury criteria, have been implemented in META post-processor.

Results and Discussion:
Based on the technologies mentioned, engineers are provided with a software tool that allows real time articulation and positioning of an HBM within an easy-to-use interface. Same time as the user directly articulates the human model using just the mouse, the biofidelic joint modelling guarantees the realistic model movements and the generation of a ready-to-run model without the need to perform a pre-simulation. Moreover, difficult positioning scenarios such as, bicycle or motorcycle riders have been also addressed and the required tools have also been developed.

Running interactively or in batch mode, the META HBM tool automatically creates PPTX and PDF reports including videos and images of GHBM's kinematics, strain contour plots, elements erosion identification, chest-bands deformations, and injury criteria calculations (Brain CSDM, Abdominal soft tissue organs SED, etc.). Moreover, time history results can be extracted from the Occupant Injury Criteria tool. Injury criteria such as HIC, BrIC, Nij, etc. are calculated. The extracted and calculated results can be compared to corresponding results of Anthropomorphic Test Devices (ATDs), while it is also easy to make comparisons between multiple GHBM simulation runs or between results from different solvers

Conclusions:
The developed software tools required for the HBMs positioning and post-processing, offer the liberty to engineers to perform the analyses they wish and give them a transparent interface across all ATD and HBM models. In this presentation, all these exciting developments and future plans will be demonstrated.