Analysing Differences of Dynamic Responses and Injury Risks of 5th Percentile Female Occupants during Frontal Impact using FE-Human Body Models Representing Eastern (Chinese) and Western (US/EU) Human Body Dimensions

Jie Yang, Christian Mayer, Satyajit Pal, Pronoy Ghosh, Bernd Brueckner, Jinhuan Zhang

I. INTRODUCTION

Numerical Human Body Models (HBMs) are being used nowadays as a supplemental tool for the development as well as assessment of occupant restraint systems. These models offer additional evaluation aspects concerning optimised system design especially for *real life safety* within an automotive environment. However, most of the HBMs are only available in certain standardised sizes, e.g. 50th and 95th percentile males, 5th percentile female etc., which currently only represent the build of population in western (US/EU) countries. In general, human body anthropometry dimensions vary greatly among different countries, regions and ethnicities in size, geometry and weight. Therefore, the body dimensions and proportions of all body parts of the available HBMs can be different from that of the eastern (Chinese) population respectively, which might also have an influence on injury risks and dynamic responses assessed by the HBMs [1]. Therefore, HBMs representing different populations are often aspired, which require a fast and reliable method for modifying the HBMs according to specific human body parameters. This paper addresses a generic geometry scaling method which can be used to adapt the size of an HBM based on several specific parameters. In addition, a digital HBM representing the 5th percentile female of the eastern (Chinese) population was developed based on the THUMSD-F05 [2][6] model, which is an anthropometrically correct HBM developed by Daimler AG and represents the 5th percentile female of the western (US/EU) population, by applying this geometry scaling method. In a further step, the position and posture of the HBMs were based on ergonomics instead of following those used for the dummies, so-called *design posture*, which is the conventional approach. The dynamic response and injuries of the eastern and western 5th percentile female HBMs during frontal impact were obtained. The values of injury metrics for the head and thorax of the eastern 5th percentile female HBM are less than those of the western 5th percentile female HBM. However, the values of injury metrics for the neck and lower extremities of the eastern 5th percentile female HBM are greater than those of the western 5th percentile female HBM. Besides, the kinematics responses of the two HBMs are obviously different, which would also have influence on the injury risks of occupants, and the optimisation strategy of restraint systems could be proposed based on the simulation results.

II. METHODS

An HBM representing the 5th percentile female of eastern population was developed based on the THUMSD-F05 model using an appropriate geometry scaling method. To ensure the two HBMs have comparable biofidelity, the eastern 5th percentile female HBM had to be validated against frontal [3] as well as lateral impact [4] load cases, which were used for the validation of the THUMSD-F05 model. The simulation environment, restraint system and test parameters are based on the Finite Element (FE) sled model of a middle class car. The position and posture of the two HBMs adhere to ergonomic requirements, which was achieved using THUMS Adjustment and Positioning Tool for Human Body Modelling (AdaPT) [5] and LS-DYNA pre-simulation, based on the RAMSIS model of the automotive and database of driving position and posture of occupants. All simulations are conducted by a commercially available FE solver, LS-DYNA 971. The dynamic response and injury risks of the eastern and western 5th percentile female HBM during frontal impact were obtained and compared, and the optimisation strategy of restraint systems could be proposed based on the simulation results.

Geometry Scaling Method

The eastern 5th percentile female HBM was achieved by using a module in HyperMesh. The scaling factors for the HBM were calculated using the dimensions of the THUMSD-F05 model and that of the eastern 5th percentile female derived from China National Institute of Standardization (CNIS), and then different body regions were

J. Yang is a M.E student in automobile crash safety at Tsinghua University in China (Phone number: +86 18800199185; E-mail: yang-j13@mails.tsinghua.edu.cn). C. Mayer is a senior engineer in Vehicle Safety and Biomechanics at Daimler AG in Germany. S. Pal and P. Ghosh are senior engineers in Vehicle Safety and Biomechanics at Mercedes Benz R&D India. B. Brueckner is a senior engineer in Vehicle Safety and Ergonomics at Daimler AG in Germany. J. H. Zhang is Professor in the Department of Automobile Engineering at Tsinghua University in China.

distinguished according to anatomy. The geometric scaling process was conducted using Morph Volumes. Firstly, one objective body region was chosen and scaled with the calculated scaling factors, then the affected body regions needed to be restored. This process was repeated for all the other body regions. After all body regions had been scaled, the scaled HBM was obtained. Any deviation of dimensions between the scaled HBM and CNIS database were then evaluated. If the deviation is too large, a new scaling factor should be calculated and the scaling process should be repeated until any deviation of all body regions are within the accepted limit. Lastly, after checking and modifying the elements, the eastern 5th percentile female HBM was obtained.

Computational Modelling

The two HBMs should have comparable biofidelity, thus the validation load cases for the scaled HBM are the same as those of the THUMSD-F05 model. As a result, the scaled HBM was validated against frontal [3] as well as lateral impact [7] load cases. The overall biofidelity score of scaled the HBM in lateral impacts is 5.98 and the score of the thoracic region is 8.55, which predicted good biofidelity. For frontal impact, the simulation results of thorax impact force and deflection are in line with the response of the test.

TABLE I

VALIDATION LOAD CASES OF THORAX REGION IN LATERAL IMPACT

Region	*Ui*	Impact Condition	$V_{i,j}$	Response Measurements	$W_{i,j,k}$	Ratings	*Bi*
Thorax	10	Thorax test 1	$V_{4,1}=9$	Pendulum force	$W_{4,1,1}=9$	10	$B_4=8.55$
		Thorax test 2	$V_{4,2}=9$	Pendulum force	$W_{4,1,2}=9$	10	
		Thorax test 5	$V_{4,5}=7$	Thorax plate force	$W_{4,5,1}=8$	5	
				Peak T1 Y acceleration	$W_{4,5,2}=7$	10	
				Peak T12 Y acceleration	$W_{4,5,3}=7$	5	
		Thorax test 6	$V_{4,6}=7$	Shoulder & thoracic plate force	$W_{4,6,1}=9$	5	
				Peak lateral displacement of T12	$W_{4,6,2}=5$	10	

One innovation of this research is to position the eastern and western 5th percentile female HBMs based on ergonomics, which was evaluated with RAMSIS. The sled model and the restraint components used in the simulation came from a middle class car which has been validated for various frontal impact scenarios. By using RAMSIS, the most probable driving posture of HBMs, as well as the position of the steering wheel and seat in the sled model can be determined for the crash simulation. The desired posture of HBMs was obtained by using AdaPT software and pre-simulation in LS-DYNA. The positions of the HBMs, steering wheel and seat were adjusted in PRIMER. The crash pulse of the simulation was obtained according to FMVSS frontal crash tests. All simulations were conducted by a commercially available FE solver, LS-DYNA 971.

III. INITIAL FINDINGS

Some injury metrics are proposed to compare the injury risks of the two HBMs, as shown in Table II.

Table II

PROPOSED INJURY METRICS OF HBMs

Body region	Injury metrics	Body region	Injury metrics
Head	HIC (head index criteria); CSDM (Cumulative Strain Damage Measure)	*Thorax and ribs*	Deflection of Sternum and 4 Points Measurement; Plastic strain and stress
Neck	Acceleration of T1 & C1	*Lower Extremities*	Section Force

It can be seen from the simulation results that the HIC_{36ms} and CSDM of the eastern 5th percentile female HBM are both less than those of the western equivalent. However, the eastern 5th percentile female HBM has more rotational motion about the Z axis during contact with the restraint system, which caused the eastern 5th percentile female HBM almost to miss the airbag in the crash. The neck acceleration of C1 and T1 of the eastern HBM are greater than those of the western HBM. The axial force of the left and right femur of the eastern HBM is greater than those of the western HBM.

The chest deflections at mid-sternum and four additional points were introduced to assess the risk of sustaining thoracic injuries and rib fractures. The chest deflections of the eastern HBM are less than those of the western HBM in the corresponding positions. For the eastern HBM, the deflections of five points are obviously different, while for the western HBM, the differences between the five point deflections are not so distinct. These are in line with the observation that the kinematics of the eastern HBM has more rotational motion about the Z axis during interaction with the restraint system. The risk for thoracic injuries and rib fractures can also be assessed by measurement of rib strain and stress. Both the maximum strain and stress of the western HBM are greater than those of the eastern HBM. However, the area with higher plastic strain and stress in the thorax region of the eastern HBM are greater than those of the western HBM.

The eastern 5th percentile female HBM has more rotational motion about the Z axis which caused a different kind of interaction with the airbag during the crash and might be one reason for the varied injury risk. This could potentially be optimised by changing the parameters of the seatbelt load-limiter.

IV. DISCUSSION

This paper investigated whether a virtual HBM could be used as an appropriate tool to evaluate the dynamic responses and injury risks of the eastern and western 5th percentile female population, and some optimisation strategies are proposed based on the simulations. One limitation of the research is the uncertainty of the position of anatomy reference points on the HBMs, which will affect the dimensional measurement of body regions. Besides, the scaling of the HBMs is based on exterior dimensions, and the differences of bones and internal organs have been ignored due to the absence of data. Furthermore, injury criteria have not been defined for the HBM so far. Hence, currently the assessment is based on the comparison of the above mentioned injury indicators.

V. REFERENCES

[1] Cummings P et al., Epidemiology, 2002.
[2] Ghosh P et al., LS-DYNA Forum, 2014.
[3] Kroell, C.K. et al., Stapp Car Crash Conference, 1974.
[4] Been B et al., NHTSA, 2007.
[5] Desai C et al., IRCOBI,2012
[6] Ghosh P et al., IRCOBI, 2014
[7] ISO/TR 9790, 1999