A Parametric Study of Submarining for Obese Female Passengers using Morphed Human Body Models

Dongjin Lee, Inju Lee, Sungrae Kim, Hyung Joo Kim, Taewung Kim, Greg Shaw

Abstract In frontal crashes, obese occupants frequently suffer from submarining injuries due to out-of-position belt fittings. To improve safety restraints for the specific body physique, a FE Human Body Model (HBM) is effective since it is highly bio-fidelic. In this research, an HBM was validated through comparison with two cadaver tests. For it, the 50th %tile male was scaled to a female size and the abdominal area was morphed to represent the obesity. Moreover, submarining conditions were successfully found through a parametric study using the validated model.

Keywords Human Body Model (HBM), female abdominal obesity, submarining injuries, morphing, frontal crash

I. INTRODUCTION

In frontal accidents, abdominal injuries are more significant than head or chest injuries in spite of a great improvement in restraint systems. The Crashworthiness data system showed that abdominal injuries ranked as the 3rd most severe among AIS 4+. Indeed, more than 60% of abdominal injuries are caused by seatbelt [1], since the lab belt apply loads on abdomen or organs rather than pelvic bone [2]. Moreover, obese occupants suffer from submarining more easily than non-obese occupants [1], because the obesity causes the lap belt to ride up on the stomach rather than staying on the lap [3].

Automotive industries have developed restraint systems using anthropometric test devices like the HybridⅢ dummies, covering a wide range of body shapes from 5th %tile female to 95th %tile male dummies that are not sufficiently bio-fidelic, not easy to modify due to the price and sometimes not necessary yet based on the regulations. In order to reflect real accident environments, a more sophisticated approach is inevitable such as using a FE HBM. It has significant advantages with regards to cost for obtaining injuries kinematics comparing the experimental method.

In this article, HBMs were validated using two cadaver tests to reproduce submarining injuries of obese females under the out-of-position belt fittings. With validated models, a parametric study was successfully done to find primary risk factors yielding submarining.

II. METHODS

The default test condition is the 56kph NCAP frontal crash for the passenger side. The cadavers had 24.2 and 21.9 BMI at each test (1-2). To create the models, the GHBMC M50 was positioned and scaled based on 3D motion data recorded in cadaver. Also, lap belt angles as influential factors to submarining were precisely consistent between the simulations and the experiments (Fig. 1-2).

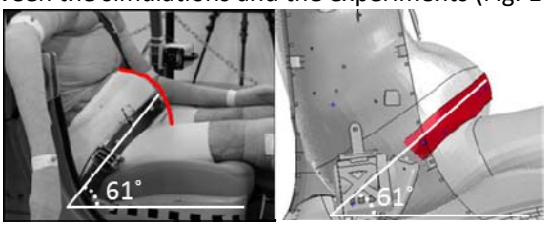

Fig. 1. Lap belt angle was set to 61 degrees with the seat forward 100mm from rearmost track position for Test 1 (Simulation model in Right)

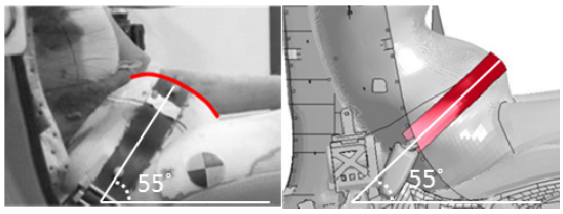

Fig. 2. Lap belt angle was set to 55 degrees with the seat rearmost track position for Test 2 (Simulation model in Right)

III. RESULTS

In simulations, morphed models presented very close kinematic behaviors to the experiments.

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Fig. 3 show pelvic rotation angles in Tests 1-2. In Test 1, the pelvis rotated forward, while the pelvis rotated backward in Test 2. Between simulations and experiments, similarities of the rotations were checked using the normalised RMSE. The percentage of it was 24.6% in Test 1 and 18.4% in Test 2. Also, the value of lap belt force was 10.2% in Test 1 and 5.5% in test 2 (Fig. 4).

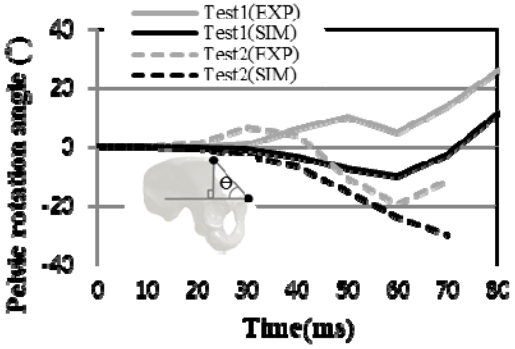

Fig. 3. Comparison of pelvic angles between cadaver tests and simulations in Tests 1-2

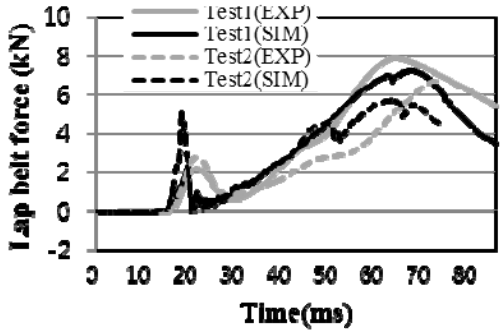

Fig. 4. Comparison of lap belt force between cadaver test and simulation in Tests 1-2

Based on the validated GHBMC models, a parametric study was conducted to find the optimal condition using a 2014 Hyundai Elantra. Significant sensitivities on submarining were observed by two parameters: seat position and belt height as shown in Fig. 5. To lessen submarining effects, the seat was placed at the rearmost and the lap belt height was lowered (Fig. 6).

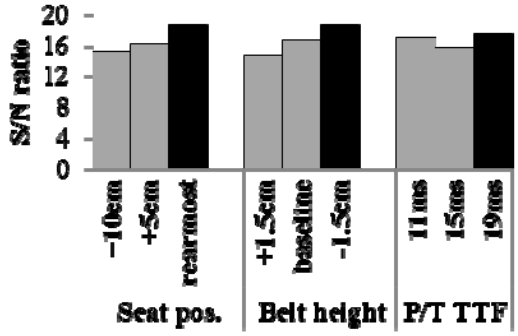

Fig. 5. Sensitivities on submarining in three different parameters (Seat position, Belt height and P/T TTF)

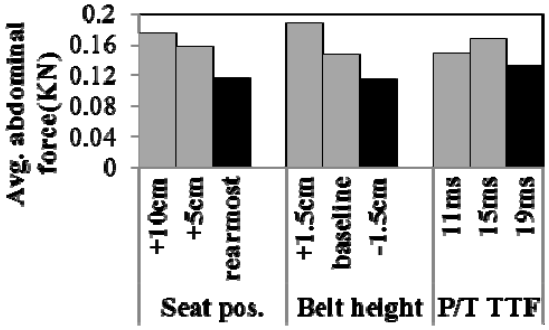

Fig. 6. Averaged abdominal forces in three different parameters (Seat position, Belt height and P/T TTF)

IV. DISCUSSION

The morphed HBM showed similar kinematics to the cadaver tests. However, the GHBMC model used is too limited to include reliable pelvis fractures, which may affect kinematics slightly different in each case. In this vein, future work can include further investigations into bone characteristics such as the difference in material properties and nonhomogeneous finite element modelling according to the age, gender, porosity of the bones and BMI of the occupants considered.

V. CONCLUSIONS

FE HBMs were capable of representing actual submarining as long as the abdominal geometry is correctly morphed and other crash environments are equivalently satisfied to the cadaver tests. Using the validated models, the optimal combination was found: 1) seat positioned at rearmost, 2) lower lap belt wearing than average.

VI. REFERENCES

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[2] J. Uriot, Stapp Car Crash J, 2006.
[3] M. R. Reed, Stapp Car Crash J., 2013.