Validation of Abdominal Characteristics under Lap-belt Loadings using Human Body Model Morphed to an Obese Female

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I. INTRODUCTION

In motor-vehicle frontal crashes, occupants often suffer from abdominal injuries when the lap-belt excurses over the pelvic bone, commonly referred to as submarining. In [6-7], the abdominal injuries induced by the seatbelt can also cause secondary damages, such as incarcerated hernia, renal trauma, etc. Nonetheless, submarining injuries have barely been surveyed because most crash dummies are not sufficiently biofidelic, especially to represent the kinematics and compliance of the abdominal area.

This paper aims to validate the abdominal kinematics with respect to the lap-belt by employing similar abdomen shape and optimizing the material properties of the abdomen flesh. Sensitivity analysis was performed on seating postures, belt positions, belt pulling speeds and belt pulling forces. The finite element (FE) human body model developed by Global Human Body Models Consortium (GHBMC) was used as a baseline model for morphing and its responses were compared to those of the post mortem human subjects (PMHS).

II. METHODS

Belt Pull Test

Two female PMHS were tested under lap-belt loading conditions in a seated posture (Fig. **1**). (a) The steel belt cables were pulled up to 4 m/s of initial pulling rates by a pneumatic cylinder. The pulling force was recorded by loadcells and the maximum force was limited by a honeycomb so as not to cause incurable injuries to the PMHS. (b) A rigidised belt [14] was placed on the abdomen and connected to the belt cables. (c) Almost every other vertebra, from C7 or T1 to sacrum, were mounted onto the upper and lower spine mounts, which were attached to the seat base via six-axis loadcells (Model 2554AJ). (d) A five-axis loadcell was mounted under the seat to measure the reaction forces and moments. (e) The femurs were amputated and constrained to the seat bottom to prevent upward motion. (f) Two sets of optical displacement and strain mapping systems were used to track the 3-dimensional motion of the belt and deformation of the skin. The force and moments from loadcells were filtered using CFC180 filter, and the belt displacement and kinematic data was not filtered.

Subject-specific Finite Element Modelling and Analysis

1) Scaling, Morphing and Positioning of the Human Body Model

The 50th percentile male GHBMC model v4.2 was scaled in part-by-part manner according to PMHS procurement. The scaled model has less than 2% of geometric difference in pelvic bone compared to the PMHS. A single analysis was performed using spring and damper to settle the FE model – abdominal flesh area was morphed to fit PMHS configuration afterwards (Fig. 3).

2) Computational Modelling and Results

The belt pull test was simulated with the aforementioned GHBMC model (Fig. 4). Prescribed constraints were equally applied onto the vertebrae as was done with PMHS. The lap-belt was positioned on abdominal skin properly relative to ASIS, and CFC60-filtered displacement was used for an input. The GHBMC default material property and a modified property (e.g. bulk and shear modulus, compressibility, etc.) of abdominal flesh were employed.

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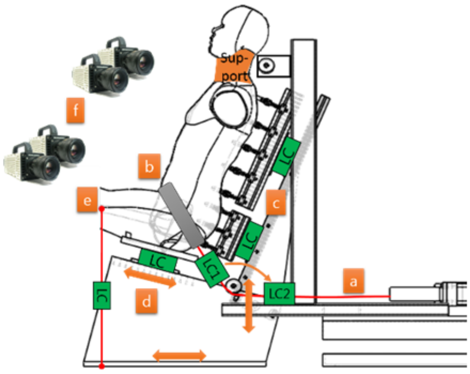

Fig. 1. Schematic of belt pull test rig.

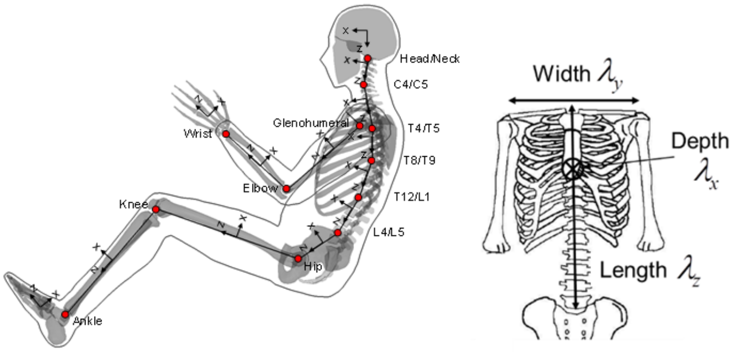

Fig. 2. Body segments for scaling.

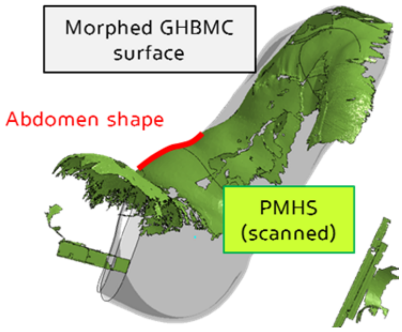

Fig. 3. Morphed FE model after positioning.

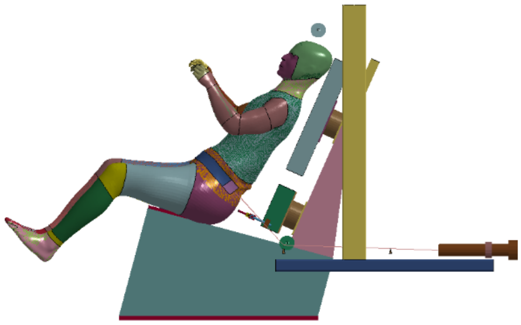
Fig. 4. Side view of integrated model.

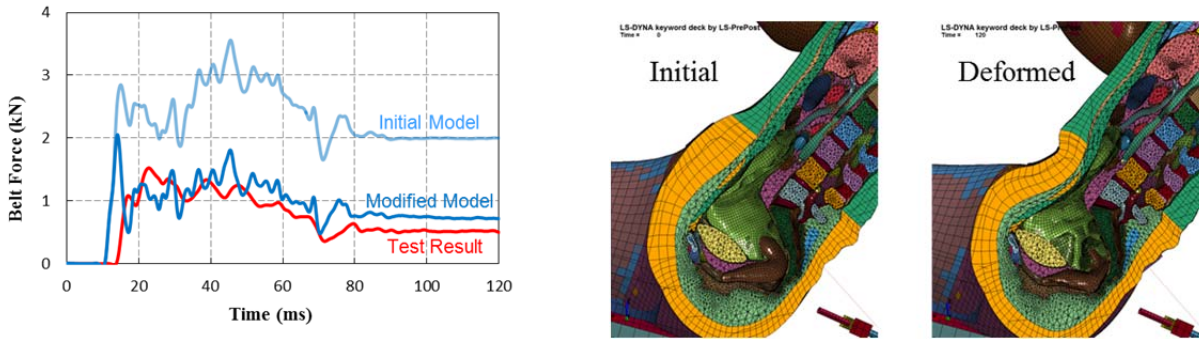

Fig. 5. Simulation results: (*left*) comparison of belt forces; and (*right*) abdominal configurations.

III. INITIAL FINDINGS

The belt force is very sensitive to the material property of abdomen as well as its configuration. When the default (initial) material property was used, the belt tension was greater than those of the PMHS. This is partially because the female PMHS can also have different proportions of muscles and fat from those of the GHBMC model which was morphed from 50th percentile male.

Considering that the prescribed displacement control is used in FE analyses, material property directly plays an important role as the stiffness of the abdomen. A small difference in abdominal compression shows a huge change in belt force and excursion. Current work showed higher stiffness in simulation than PMHS tests, and therefore it is challenging to use enhanced material card in LS-DYNA environment since this work only employs simplified rubber model or viscoelastic model to represent the abdomen material.

IV. DISCUSSION

Modified geometry and kinematic properties using GHBMC were validated and compared with PMHS tests. Future works mainly include: (a) to use various types of material property (e.g. non-homogeneous material to represent the muscle or fat layers); (b) to further investigate internal shape of flesh; (c) to tune contact conditions near organs or friction coefficient of the belt; and (d) to validate detailed material responses through cadaver trial tests. This enhanced model can be used to investigate submarining risk during vehicle crashes.

V. REFERENCES

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