Development and Validation of Liver Model with the 50th Chinese Human Body Finite Element Model

T.Y. Du, J.Q. Chen, F.C. Lan, Z.W. Ma

I. INTRODUCTION

Human hepatic dynamic responses and injuries associated with frontal impacts and lateral impacts were investigated and predicted using a simplified human body finite element (FE) model with detailed liver model for an average Chinese adult male. The developed model in this paper consists of a geometrically detailed liver model, simplified models of thoracic-abdominal organs, and the human skeleton model. Then, the whole model was validated at various impact speeds by comparing predicted responses with Post Mortem Human Subject (PMHS) experimental results in frontal and side pendulum impacts. The force-deflection characteristics of the thorax-abdomen were in good agreement with the experimental data. The validated model was then used to study liver dynamic responses and injuries in various simulated impact situations.

II. METHODS

Developing the FE model

The full human body finite element model was constructed from high resolution CT data of a Chinese male 50th percentile human subject. We detailed the geometry of the liver model and made reasonable simplifications of other organs. The geometry models of internal soft tissue and the liver were edited in Hypermesh. Then the soft tissue geometry model was assembled with a ribcage model by fitting it in an anatomic position. The assembling method used for the liver and soft tissue model was the Boolean operation, which means subtracting the corresponding volume the liver occupy from a soft tissue model according to the liver anatomic location, below the diaphragm in the upper right quadrant of the abdomen. The liver geometric model was scaled to 1.01 times before the Boolean operation in order to leave enough space surrounding the liver defining the interface properties, narrowing the scale to actual size based on the previous reference point. The liver was modelled as one part with high quality geometry, in order to distinguish the exact position of stress and strain concentration. The main ligaments like coronary ligament, round ligament, left/right triangle ligament were built with spring elements as the connections with other parts.

Material modelling

The 3rd Ogden material model was chosen for parameter identification of liver parenchyma uniaxial compression experiments. The FE programme Abaqus (SIMULIA Inc.) has been used for the inverse analysis. The values evaluated for parameters are $\mu_1 = -0.61518, \mu_2 = 0.09564, \mu_3 = -0.15972, \alpha_1 = -2.95491, \alpha_2 = 23.1656, \alpha_3 = 18.28425$. The correlation coefficient between the experimental and fitting curves was calculated as 0.99. Validation of the liver model was performed in incremental steps. First, material properties of liver parenchyma were evaluated individually on the simulation of tensile tests at $0.01s^{-1}$ strain rate [1]. Next, validation was performed on liver model against the experiment [2]. It can be seen that the simulation result of the liver model appeared in good agreement with the test data. The FE liver model has been proved to be available with the two methods above.

The bony structures of the human model were assigned as elastic-plastic material characteristics and the soft tissue such as muscles, internal contents, cerebrum, cerebellum and brainstem were modelled as solid elements with linear viscoelastic material. The material properties assignment were summarised from papers and calibrated in model validation.

Model validation against PMHS data

PMHS pendulum tests to thorax for frontal impacts [3] and lateral impacts [4] were simulated to validate the response of the thorax model by comparing model predictions with experimental data in terms of forces and force-deflections. In frontal impact simulations, two sets of experiments were conducted with different velocities (6.7m/s and 7.33m/s). In lateral impact simulations impact velocities of 4.0m/s, 5.5m/s, 6.73m/s were chosen to check the validity of the model within the range of cadaver corridors.

T.Y. Du is an engineering PHD student in Biomechanics at South China University of Technology in Guangzhou (dty_525@163.com, 0086-15521335995). J.Q. Chen is Professor of Automotive Engineering in the School of Mechanical and Automotive Engineering at South China University of Technology in Guangzhou.

III. INITIAL FINDINGS

Fig. 1. Whole human body finite element model

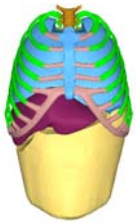

Fig. 2. Human torso finite element model

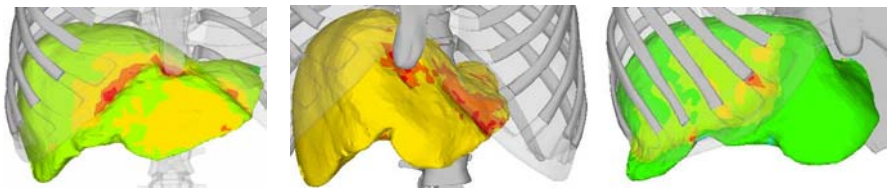

Fig. 3. Liver model pressure contour: a) frontal impact; b) left side impact; c) right side impact

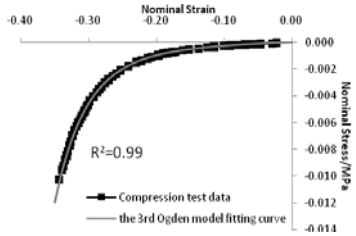

Fig. 4. The 3rd Ogden model fitting curve of compression test

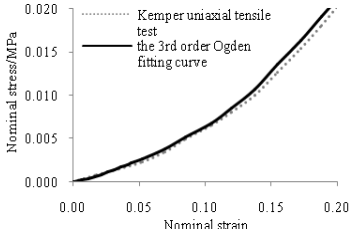

Fig. 5. The validation of the 3rd Ogden model

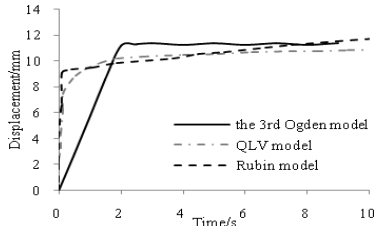

Fig. 6. The displacement-time curve of liver with a concentrated load

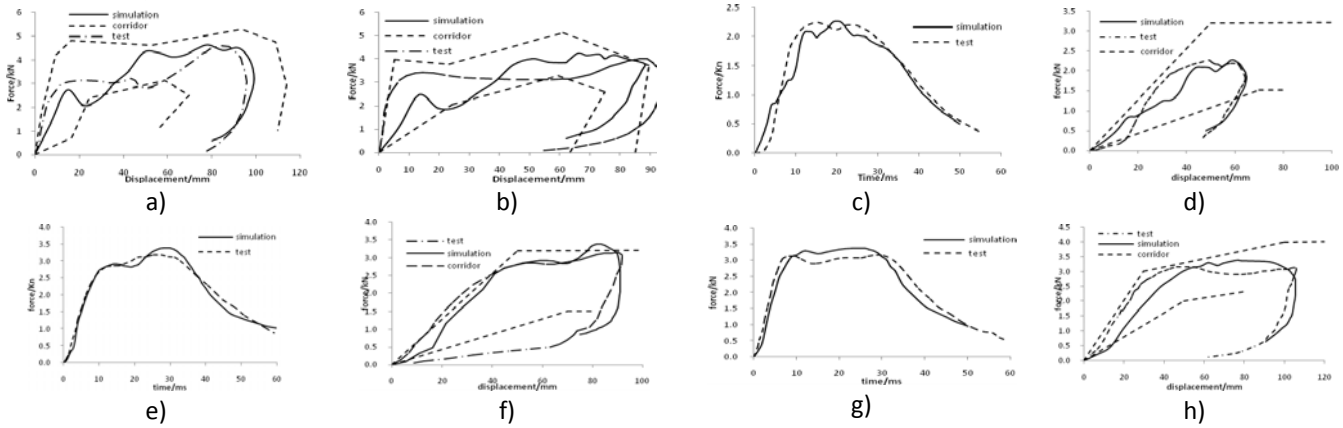

Fig. 7. Validation results in various impact speeds: a) force-deflection curve in 7.33m/s; b) force-time curve in 6.7m/s; c-d) force-time and force-deflection curves in 4.0m/s; e-f) force-time and force-deflection curves in 5.5m/s; c-d) force-time and force-deflection curves in 6.73m/s

IV. DISCUSSION

1) Using the new method of Boolean operation in developing models of an abdominal-thoracic part was proved to be effective in making simplification in order to reduce computing time and improve the robustness of model.

2) The refinement of a human liver model concluded the optimisation of liver material parameters and structures of the liver. Validations of the 3rd Ogden model have shown that it's reasonable to simulate liver material behaviour in compression and tensile conditions. The important structures were modelled such as the right and left triangular, coronary and round ligaments. It's effective for analysing the usual injury locations during impact.

3) The validation of a human body model in thoracic impact had demonstrated that the method of developing a simplified FE thorax-abdomen model with a detailed liver model could be useful for hepatic injury assessment in various cadaveric impacts.

4) The studies into injury criteria for the liver showed that a pressure of 168.5 kPa was necessary to cause superficial laceration of the liver, while 319.8kPa caused multiple ruptures, and that moderate trauma (AIS =4 or 5) under dynamic loading occurs at a threshold stress level of approximately 310kPa. In frontal impacts, the caudate lobe, the area in contact with the xiphoid process and the positions of gastric impression and the gallbladder were predicted the most likely to sustain injury in frontal impacts at a speed of over 4m/s. In left side impacts, liver injuries were mainly predicted in the area of the left lobe beneath the infrasternal

angle and right lobe close to the falciform ligament. In right side impacts, liver injuries were mainly predicted in the area of the right lobe corresponding with the contact positions of the ribs and the spine (Fig. 3).

V. REFERENCES

[1] Kemper A et al., ESV C, 2011.
[2] Nava A et al., Med Im An, 2008.
[3] Kroell C.K. et al., Stapp Car Crash, 1971.
[4] Viano D.C. et al., Stapp Car Crash, 1989.