Biomechanical Analysis of Human Thorax and Abdomen During Automotive Impact

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Abstract. Injuries incurred to occupant during automotive frontal crashes range from every part of the human body, and especially for the thorax and abdomen. It's indeed to learn more about the impact biomechanical mechanism of human body in order to improve the impact safety of vehicles to protect the occupant. In this study, a previously developed finite model of Chinese 50th percentile male thorax and abdomen is used to study the biomechanical response under frontal impact. The stress-time, strain-time characteristics are analyzed. Quantitative results such deflection curve are obtained and indicate that the 6.7 m/s frontal impact leads to large deflection and stress which will damage the ribs, lungs and other organs. Since the experimental study with human cadavers is difficult to proceed, this finite element model based on the anthropometric data from Chinese 50th percentile male can be used to analyze the biomechanical response during automotive impact in order to improve the automotive impact safety.

Keywords: Biomechanical response · Automobile · Impact · Finite element

1 Introduction

The impact safety is one of the most important aspects during the automobile production process and it is mainly assessed by the human body injury [1]. So it's important to learn more about the biomechanical response of the human body during automotive impact in order to improve the automotive impact safety. Automotive accident analysis shows that thorax and abdomen are the most vulnerable parts which lead to death because the organs in these two parts are very important and vulnerable.

There are three approaches to study the biomechanical response of human body: (1) biological model: human cadaver or animal experiment. Mertz et al. [2, 3] have exposed the thoracic and abdominal regions of animals to frontal and lateral impacts of deploying airbags. The results showed that the same severity of injury could be produced for each impact direction for the same loading condition. However, since the animal have big difference from real human body, the experiment data is not satisfactory. Human cadaver

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is ideal experimental object, however human cadaver is rare and vary with age and gender which make it hard to do large-scale experiment. (2) mechanical model: researchers developed the crash test dummy to simulate the real human body. The crash test dummy simulates the human parts with springs, dampers and other mental parts [4–8]. By testing the flection and kinematic data, the impact biomechanical response is described. In China, Hybrid III is used in frontal impact experiment and EuroSID is used in lateral impact experiment. In the experiment of automotive impact, the crash test dummy is used to get the value of parameters such as force, acceleration and displacement and based on these basic parameters the HPC (head performance indictor), ThPC (chest performance indictor), FPC (thigh performance indictor) are calculated to indicate the automotive impact safety. Since HPC, ThPC and FPC are relative with the anthropological data, and those two kinds of dummies are based on the anthropological data from American and European, there are some differences with the Chinese people which will influence the results. (3) numerical model: the biomechanical response of human body or dummy can be modeled by either rigid-body dynamics or finite element methods. The finite element model can represent the flexibility and material behavior of the human body in detail and accurately but at a significantly higher computational cost. However, with the development of high-speed computing method, the finite element modeming technology has been used to predict the biomechanical response during automotive impact [7].

In this study, a previously developed finite element model of thorax and abdomen base on the Chinese male 50th percentile data is used to do some simulation on the automotive frontal and side impact in order to analyze the biomechanical response of the human body to improve the automotive impact safety.

2 Methods

2.1 Finite Model and Material

The finite element model of thorax and abdomen developed previously is used in this study. Figure 1 shows a view of the model that was based on the 50th Chinese percentile male dimensions which consists of spine, ribs, heart, lungs and relative soft tissue.

The whole finite element model contains 285801 nodes and 956984 elements. The model were discriminated into 2 kind of material. The constitutive laws for all the tissues in this model are either considered as linear elastic or linear viscoelastic. Hard tissues, such as spine, ribs were modelled with liner elastic solid elements characterized by the stress-strain law:

$$\boldsymbol{\sigma} = \mathbf{E}\boldsymbol{\varepsilon}, \tag{1}$$

with $\mathrm{E} = 4.2 \times \mathbf{10^6}$ Pa for spine and ribs. Where **E** is the elastic moduli.

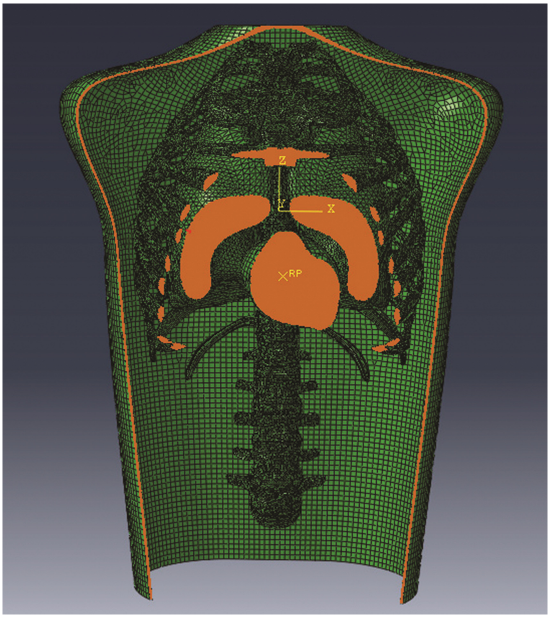

Fig. 1. Sectional view of the thorax and abdomen model

Soft tissues, such as heart, lungs and fresh were modelled with linear viscoelastic material characterized by:

$$\mathbf{G}\,(\mathbf{t}) = \boldsymbol{G}_{\infty} + (\boldsymbol{G}_{0} - \boldsymbol{G}_{\infty})\boldsymbol{e}^{-\boldsymbol{\beta t}}, \tag{2}$$

with $\boldsymbol{G}_0 = \mathbf{230}\boldsymbol{kPa}, \boldsymbol{G}_{\infty} = \mathbf{436}\boldsymbol{kPa}, \boldsymbol{\beta} = \mathbf{0.635}$. Where, $\boldsymbol{G}_0$ and $\boldsymbol{G}_{\infty}$ are short-term and long-term shear moduli, which govern the viscoelastic response. $\boldsymbol{\beta}$ is the decay factor.

The skin was modelled with elastic material, which the Young's moduli is 31.5 MPa and the Poisson's ratio is 0.45.

Contact interfaces are defined between impactor and skin, skin and ribs, ribs and lungs, spine and skin. Tied constrains are defined between the vertebrae and disks.

2.2 Impact Conditions

The impact simulation was conducted by ABAQUS software and a dynamic explicit method was used, the step time was 50 ms. Since the model was used to simulate frontal blunt impact response. The blunt used for the frontal impact simulation was modelled as rigid cylinders just as Fig. 2 shows.

The blunt was given an initial velocity of 6.7 m/s and was set to generate a mass of 23.4 kg during frontal impact simulation. The blunt was meshed using solid elements.

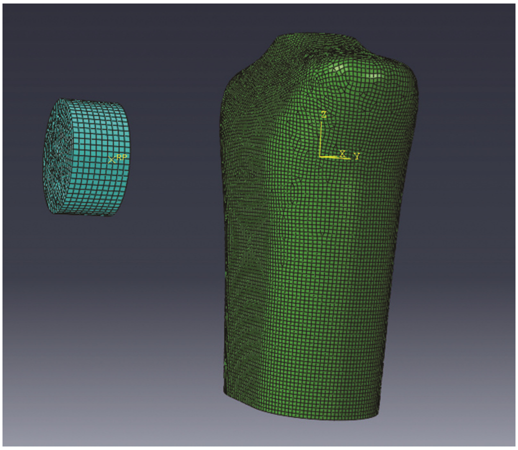

Fig. 2. Frontal and lateral impact

3 Results and Discussion

3.1 Impactor

Figure 3 shows the velocity of the impactor during the impact. From the results, we can see that the initial velocity is 6.70 m/s, the collision occurs at about 0.0275 s and declines because of the interaction between impactor and the human model.

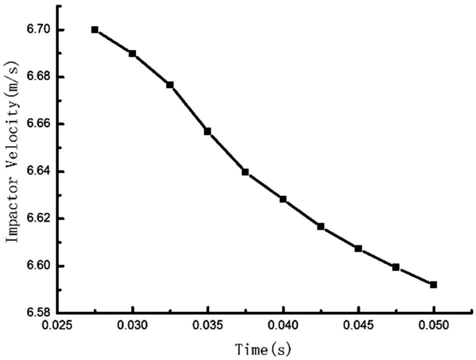

Fig. 3. Velocity of the impactor during impact

3.2 Skin

Figure 4 shows the map of displacement and stress after frontal impact. The impact area has the biggest deflection and decreases outwards. The stress concentration area occurs outside the impact area where large curvature occurs such as shoulders.

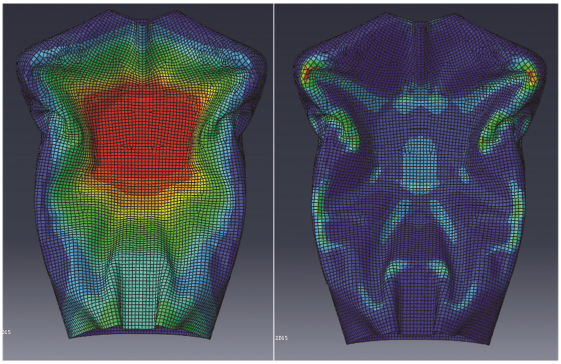

Fig. 4. Displacement and stress of skin

Figures 5 and 6 show the relationship of stress-time and strain-time during frontal impact. In about 0.01 s, the stress and strain increase to the maximum which are 7 × 〖10〗^5 Pa for stress and 2 × 〖10〗^(-2) for strain. Then the stress and strain decrease to the half maximum slightly at 0.05 s. From the results we can conclude that the best time to reduce the injures during impact is the first 0.01 s so that we can improve automobile's impact safety at that time.

3.3 Ribs and Lungs

Figure 7 shows the stress and deflection characteristics of ribs under the 6.7 m/s frontal speed. The deflection and stress becomes larger along with the impact. Since the bone was set as elastic material, there was no fracture, however the high deflection rate will indicate the injury of ribs.

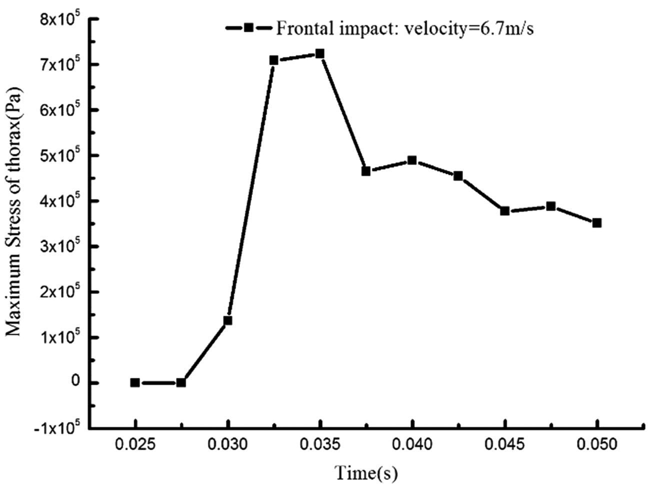

Fig. 5. Maximum stress of skin

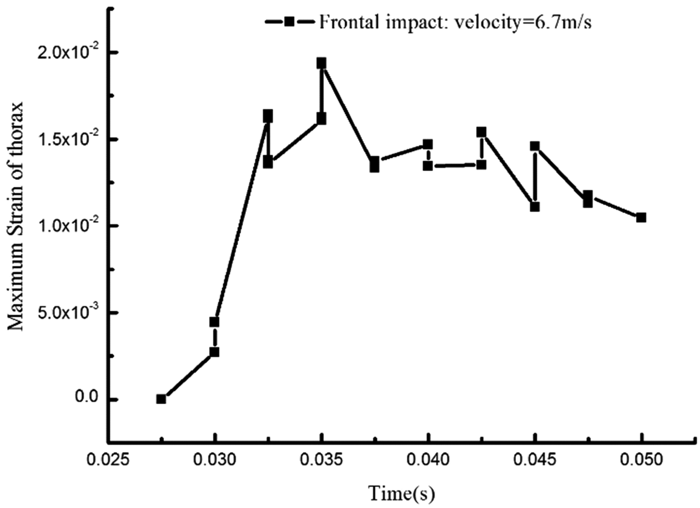

Fig. 6. Maximum strain of skin

Figure 8 shows the deflection of the lungs during the frontal impact. The deflection starts at about 0.035 s when the ribs deforms to contact the lungs. The deformation of lungs is based on ribs' deformation. From the results, the lungs have a large deformation about 10 cm at 0.050 s which will significantly damage the soft tissue of lungs.

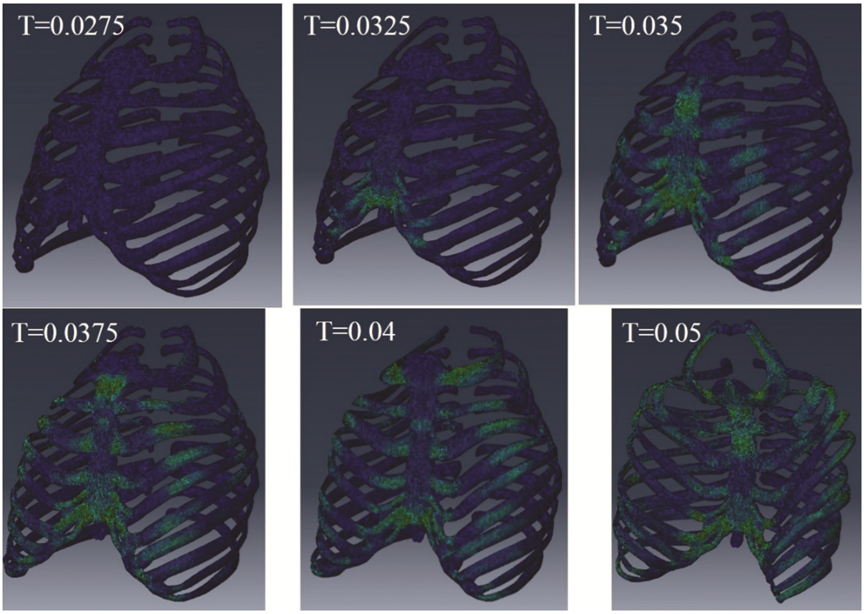

Fig. 7. Biomechanical response of ribs to frontal impact

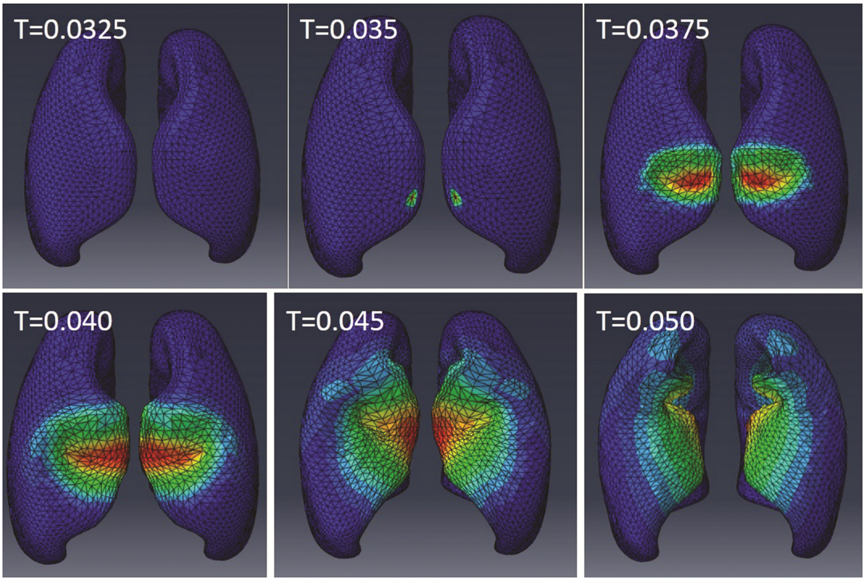

Fig. 8. Biomechanical response of lungs to frontal impact

4 Conclusions

The different injury types during impact appear to be dependent on the rate of loading because the soft tissues' viscoelastic property. Low speed impact's injury mechanism is compression of the organs and high speed impact will injure the occupant by transmission of a pressure wave. From the results of frontal impact simulation, we can see that the stress-time curve begins with a primary inertial impact peak because the human part at the impact site is quickly accelerated to the speed of the impact blunt. The maximum compression appears after the force plateau has begun to decline. The force response of the simulation shows good agreement with the experimental data from other literatures.

The results from this study can be used to analyze where and how the human tissue was affected during automotive frontal impact. Then we can try to improve the automotive impact safety targeted. Since the finite model was developed based on Chinese anthropology, it will play an important role in the development Chinese crash test dummy.

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