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Injury analysis on 6-year-old pediatric occupant horax during school bus frontal crash

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Abstract: In order to study the biomechanical response and injury of pediatric occupant during school bus accidents, a previously established six-year-old pediatric biomechanical thorax human model are upgraded and verified by lateral and oblique impact experiment. A school bus frontal crash simulation model is used to study the injury of ribcage, lungs and heart, with 3-point safety belt as restrain system. Simulation results show that maximum Von Mises strain of ribcage is 0.02, the max first principle strain of lungs and heart are 0.246 and 0.270, respectively, indicating they are more easily injured than bones. Lung injury are likely to concentrates on the superior lobe near the apex of lungs, and the most endangered area of ribcage lies in the sternum where safety belt is worn. The thorax model can be used to further optimize the school bus restrain system and to study the injury mechanism in different crash conditions.

Key words: 6-year-old child, School bus safety, thorax injury, finite element analysis

1 Introduction

According to the statistics, pediatric occupant under the age of 15 made up 6% of the enormous casualty in traffic accident in China. Among which, children under the age of 6 account for 40% of the number of injury, and over half of the fatal ones [1]. Due to the particular condition in China, school bus accidents frequently happen, endangering over 5 million students' safety [2]. Thus, the youngest and most vulnerable group on school bus, 6-year-old child occupants, suffer great injury in head and thorax [3]. However, current restrain system is mostly designed based on adults, child oriented safety seat and booster seat also have not been used on school bus. Meanwhile, regulations on child demands less than adults. It is clear that further research on child occupant needs to be carried out urgently.

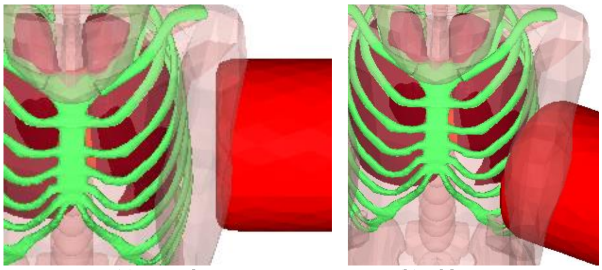
Focusing on the above problems, biomechanical injury model and post human mortal test were conducted to study occupant injury mechanism [4]. Wei [7] established a detailed model, including bones, soft tissue, muscle and skin, but the detailed model was verified by frontal and side impact test data, but there was not yet injury study. Lv [8] carried out lateral/oblique impact experiments simulation. Jiang [9] established a 10-year-old human model, and the dynamic response in different conditions, such as CPR loading, imapctor and safety belt loading, are all verified. At present, there are several accurate biomechanical pediatric thorax models, but there are few model that can be used directly in a full size crash condition. On the other hand, common dummies used in crash is not capable of bone and soft tissue injuries analysis.

In this paper, a verified school bus frontal crash model and a previously built 6-year-old biomechanical thorax model [10] are used. Thoracic responses under different crash accelerations are studied, and pediatric bone, heart and lungs injury are analyzed. Fitting relation between biomechanical injury and thorax injury criterion is established, and thorax injury threshold is predicted, laying theoretical foundation for pediatric injury mechanism research and school bus restrain system development.

2 Method and Material

2.1 6-year-old thorax human model

Pediatric thorax is previously built by revised modeling from CT scan images, including important injury parts, like sternum, ribcage, heart and lungs. Since then, simulated skin and muscle around thorax are added. Based on Ouyang's cadaver thoracic impact test [11] as verification, more dynamic responses of the model are acquired. Lateral and oblique impact simulation tests [12] are conducted to further increase the accuracy of the model, as shown in Fig.1. Results are shown in Fig.2 to Fig.5. It can been seen that under three impact velocity, the responses of pediatric thorax model are within the force-deflection channel, which was acquired by Parent's re-analysis of Ouyang's test data [14]. The VC values also exceeds 1m/s in accordance with lungs injuries during test. The results of lateral and oblique impact are also in good agree with test corridor. Thus, the pediatric thorax model is accurate, has a high degree of biological resemblance, and can be used in further crash analysis.



(a) Lateral (b) Oblique

Fig.1 Simulation model of lateral and oblique impact

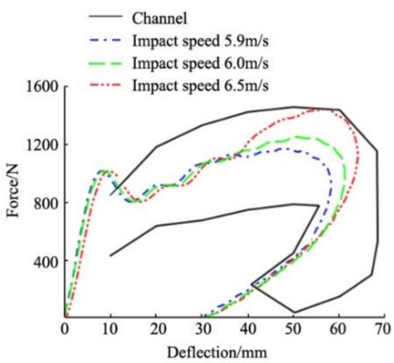


Fig.2 Validation channel based on cadaver tests and simulation results

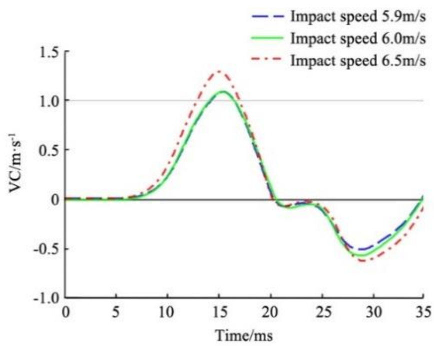


Fig.3 VC of simulation model under different impact speeds

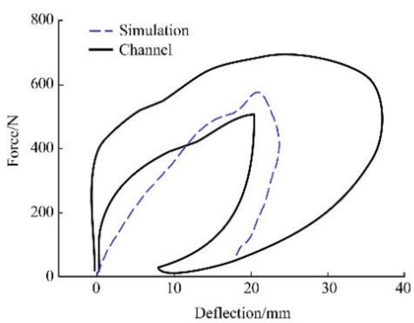


Fig.4 Validation channel based on lateral impact and simulation results

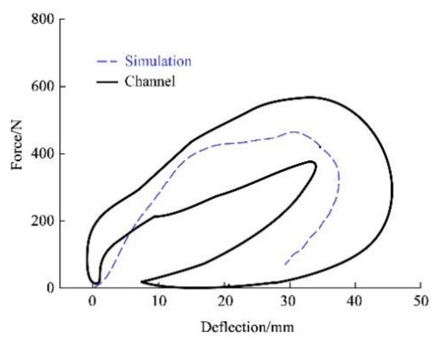


Fig.5 Validation channel based on oblique impact and simulation results

2.2 School Bus Frontal Crash condition

A verified school bus frontal crash simulation model at the speed of 30km/h is used as loading condition. The pediatric human model built is placed on the school bus seat and restrained by 3-point safety belt. The position of D-ring is determined by optimization result [15]. Thorax acceleration, deflection, VC, safety belt force, stress and strain of bones and organs are acquired. Simulation model is shown in Fig.6.

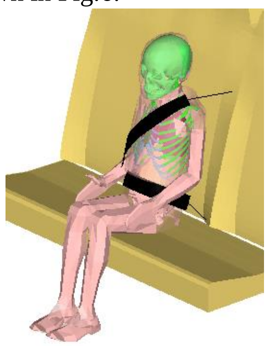


Fig.6 Simulation model

3 Injury analysis

3.1 Ribcage injury

Ribcage injury is determined by failure strain, which is considered to be 0.04 [16]. The strain of costicartilage during simulations is far below its failure value, therefore it is not discussed in this paper. On this basis, the nephograms of the ribcage is shown in Fig.7, in which the maximum strain is set to 0.04 to better indicate injury. It is obvious that high strain area lies in the middle of sternum where safety belt lays on, resulting in relatively high strain in the second pair of ribs. The maximum strain of sternum is 0.02, indicating that no injury occurs. It is worth noting that the left side of ribcage sustain much more damage than the right side, with a maximum strain of 0.017 compared to 0.011 on the other side. It is caused by the free motion of head, neck and right arm, leading to a torso rotation during crash, thus the safety belt slips to the left thorax.

3.2 Heart and lungs injury

The dynamic response of soft tissue is complicated, the maximum first principal strain is calculated as injury criterion. The failure strain of lungs is 0.284 [17], and the contused wound threshold of heart is 0.30 [18]. Lungs and heart strain are shown in Fig.8 and Fig.9, respectively. It is observed that the superior lobe sustains severe deformation due to the compression of the first pair of ribs, but no injury occurs. The max strain of lungs reaches 0.246, meaning lungs injury is near the threshold. As for heart, the principal strain reaches 0.270. The main reason of heart contused wound is its impact with ribcage. But both lungs and heart are safe in the current legal threshold.

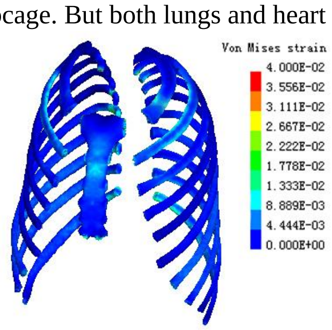


Fig.7 Von Mises strain of Ribcage

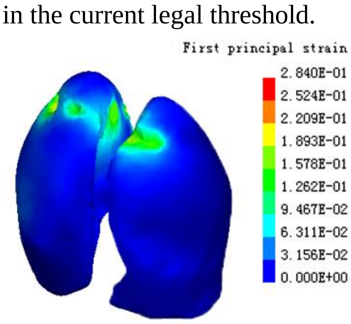


Fig.8 First principal strain of lungs

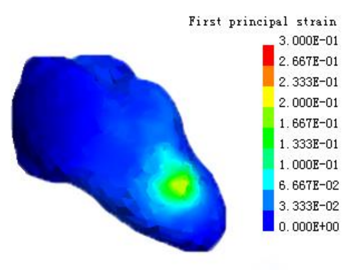


Fig.9 First principal strain of heart

3.3 Injury criteria comparison

The main injury criteria of the simulation model are shown in Table.1. T3ms and compression are around 60% of the threshold, while ribcage strain is less than 50%. Due to the low crash speed, with a proper safety belt restraining, ribcage are well protected in school bus. However, compared to VC, the first principle strain of lungs and heart reaches nearly 90% of the threshold, indicating that both important organs are in danger. This phenomenon shows that in pediatric thorax, internal organs suffer injury more easily than bones, which is the same conclusion with Maltese's research [19]. The T3ms threshold maybe higher than actual injury and needs further research.

Table.1 Injury criteria of simulation

	Simulation	Threshold
T3ms/g	18.87	30
Deflection/mm	24.30	42.6
Compression/%	17.10	30
Force/N	1364.6	/
VC/m s-1	0.792	1
Sternum Von Mises Strain	0.020	0.04
Rib Von Mises Strain	0.017	0.04
Lung First Principle Strain	0.246	0.284
Heart First Principle Strain	0.270	0.3

4 Conclusion

Based on the study of 6-year-old pediatric thorax injury during school bus frontal crash, the following conclusion can be drawn:

(1) The lateral and oblique impact further verifies the accuracy and universal property of the previous built 6-year-old pediatric thorax model.

(2) Although no injury occurs during school bus 30km/h frontal crash, heart and lungs strain reaches nearly 90% of the threshold while T3ms is only 60%. Lungs and heart suffer injury more easily than bones. The simulation results in this paper also verify that current domestic regulation is proper for 6-year-old child occupant.

(3) The dangerous area of ribcage is determined to be sternum where safety belt is laid on, and the second pair of ribs suffer the most deformation. Lung injury is most likely to occur at the superior lobe near the apex of lungs, its deformation is caused by the compression of the first pair of ribs during thorax deflection.

(4) Unlike the reversed loading in previous tests, there is a distinctive difference between left and right side of ribcage. Because the safety belt is worn, occupant's head and right arm is free to move during crash, which leads to a rotation of occupant's torso, resulting in larger loading in the left side of thorax.

Further research still needs to be conduct to build actual muscle model instead of equivalent muscle model, so that the initial respond would be in good agreement with test channel. And the relationship between injury criteria and 6-year-old pediatric thorax injury under different crash severities also need to be established.

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