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A Study of Seatbelt Position on Chest Injuries Based on Frontal Sled Impact

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Abstract: The purpose of this research is to study the chest injury outcomes caused by the seatbelt position parameters based on the bio-fidelity validated finite element occupant model. This study is conducted by the latest developed frontal impact test and the model is restrained on the occupant position by the regular seatbelt. Then, the design of experiment was used to study the parameter analysis of seatbelt height and seatbelt angle on chest injuries including chest accelerations and four-point chest deflections. The results show the belted THOR dummy can be adopted in the chest injury study. Chest injuries are sensitive to the seatbelt restraint system. Specifically, Chest injury outcomes are more sensitive to seatbelt height than seatbelt angle. This study can provide a reference to the THOR dummy development and the virtual design, and the study method can serve as a reference to the chest injury mechanism study.

Keywords: Chest Deflection, Chest Acceleration, THOR Dummy, Seatbelt

1 Introduction

With the widespread usage of safety equipments in the vehicle, all types of injuries have been greatly reduced, However, the number of injury cases is still very high 错误！未找到引用源。. About 70% of the traffic injuries are related to the chest injuries [15]. Thus, more attentions should be paid to the chest injuries in traffic accident [1],[6].

THOR (Test Device for Human Occupant Restrain) dummy is a newly developed and good bio-fidelity frontal impact dummy especially for chest injury study compared with other dummies like Hybrid III [14]. Shaw [12] performed a series of THOR dummy tests under Gold Standard (GS) frontal impact environment. All these tests can validate the biomechanical study. All the deflections in the THOR are measured by the sensor of Infrared Telescoping Rods for Assessment of Chest Compression (IR-TRACCs) according to the spine [12]. The impact kinematics are recorded by the VICON capture system [13] so as to compare the different kinematical outcomes between PMHS and dummy during the frontal impact. The bio-fidelity of THOR has been widely validated under the condition of frontal impact, which concludes that this model can be used in the continuous studies [16].

The previous test study [2] and simulation study [9] show that chest injury outcomes like rib fractures and strain/stress distributions are highly dependent on the boundary conditions. As the primary injury index of the chest, it is difficult to quantitively determining the correlation between constraint system and chest protection efficiency. Studies indicate chest injury in the vehicle accidents are mainly from the seatbelt loadings [3]. Therefore, the study of protection efficiency is more critical. Shang [11] simply discussed the relationship between seatbelt and injury indexes. Peak [7] simply studied the injury outcomes caused by the seatbelt. But the more detailed quantitively studies about the influence of seatbelt loadings on the chest injuries is not sufficient.

This study utilizes the mechanical dummy to reconstruct the sled impact based on the seatbelt position loadings on the chest injury outcomes. Combined with the statistic method, the parameter study and sensitivity study were conducted. Further, the results can provide a reference to the improvement of the restraint system and dummy model.

2 Method and material

2.1 Test equipment

A series of THOR dummy tests (S156-S158) were performed under 40 km/h in the Gold Standard test environment (Fig1). The torso spine angle of THOR dummy was adjusted at Super Slouched position. The impact process was recorded by high speed camera system. and the seatbelt was manufactured by Narricut (6-8% elongation rate, 26.7 kN minimum tension force). The mechanical properties of seatbelt were obtained via tension test [13].

The present THOR dummy used was the THOR 50th male dummy with Mod-Kit/Metric hardware developed by NHTSA (National Highway Traffic Safety Administration) [10]. The shoulder was adjusted by the Chalmers SD-3 shoulder.

The final posture of THOR was determined by the method described by Parent [8], and all the positions were arranged in angles defined by Shaw [13]. The height of THOR was 175 cm and the mass was 78 kg. The posture of THOR dummy can be determined by the adjusting joint angles. All the defined angles in the THOR tests were similar to each other.

Fig 1. THOR dummy sled test

2.2 Injury index

In the dummy test, the common injury indexes which reflect the chest injury were chest acceleration and chest deflections. The chest deflections can represent the rib and sternum fractures caused by the contact loadings outside the body. And these fractures are the primary consequence of the traffic injuries from the restraint loadings [4]. Thus, the chest deflection can be a useful index of the chest injury. Chest acceleration is also the main index in the chest injury to reflect the change of velocity rate which can reflect the injury of inner organs. Study shows that if the acceleration happened in a very short time, there would be no injury in the chest though the acceleration value was very high. And usually, the acceleration 60 g was defined as the tolerance of the chest injury if this value lasted for more than 3 ms.

2.3 Belted model reconstruction

THOR mechanical dummy is simple and repeatable way to conduct the chest injury study. Moreover, all the measuring points are fixed. Thus, this kind of dummies were widely used in the regulation and injury tests. THOR dummy FE (finite element) model version 2.1 was developed by University of Virginia and NHTSA (Fig 2). Overall, there were 237440 elements and 460639 nodes. The main contact methods were automatic surface to surface and automatic single surface. All the sensors and load cells in the dummy were simulated at the model with FE method.

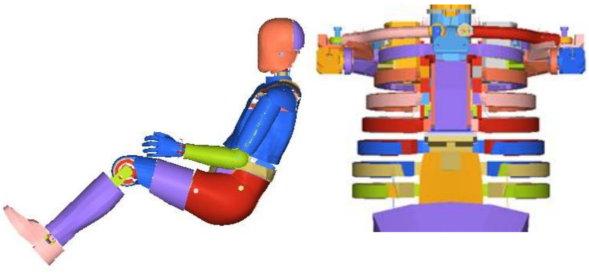

Fig 2. THOR FE model and the chest structure

The THOR model reconstruction was established according to the test S157 (Tab1).

Tab 1 THOR dummy position angles (in degree)

Test ID	Head angle	Mid sternum angle	Lower spine angle	HPT distance*（mm）	Femur angle	Tibia angle
S157	0.1	54.0	81.1	-3	4.6	36.9

*HPT distance (relative to seat center line)

According to Shaw [13], middle sternum was the ideal waypoint of the seatbelt. and the distance between top sternum and seatbelt centerline (seatbelt height B) and seatbelt angle measured from vertical line of sternum (seatbelt angle E) can define a basic seatbelt path. The range of the seatbelt height and seatbelt angle were defined according to the test. Seatbelt height changed from the top sternum to the bottom sternum and the seatbelt angle changed from 40 degrees to 60 degrees. The seatbelt was simulated by 1D seatbelt element which connected the seatbelt to the sled (seat) and 2D element which was the main part of the belt. The contact friction coefficient between THOR and belt was defined as 0.3.

Tab 2 Simulation matrix

Simulation ID	Factors (levels)	
	B	E
b1e1	1	1
b1e2	1	2
b1e3	1	3
b2e1	2	1
b2e2	2	2
b2e3	2	3
b3e1	3	1
b3e2	3	2
b3e3	3	3

Through the variation of the seatbelt position parameters, the chest injury outcomes can be analyzed. There were three levels for each factor of seatbelt height and seatbelt angle. In sum, there were 9 simulations in the study simulation matrix (Tab 2). The injury outcomes in this study were chest acceleration at the spine and the chest deflection at four locations which were upper right (UR), upper left (UL), lower left (LL) and lower right (LR). Three levels of the seatbelt height were top sternum, middle sternum and bottom sternum. Meanwhile, the seatbelt angles were 40 degrees, 50 degrees and 60 degrees.

3 Study results

The results of chest accelerations and chest deflections were used to analysis the injuries cause by the seatbelt.

3.1 Chest acceleration

THOR dummy acceleration were measured at the first and the twelfth thoracic vertebrae (Fig 3).

With the changing of seatbelt height, there would be no obvious change in T12 acceleration. In contrast, all the changes in T1 were obvious, though the peak times would shift to a later time. The fluctuation at 60 ms would become less, though the peak would not change. With the changing of seatbelt angle, T1 acceleration would shift to an earlier time and peak would decline. The fluctuations after 60 ms can be ignored. all the acceleration during the whole process was stable thought the peak would decrease.

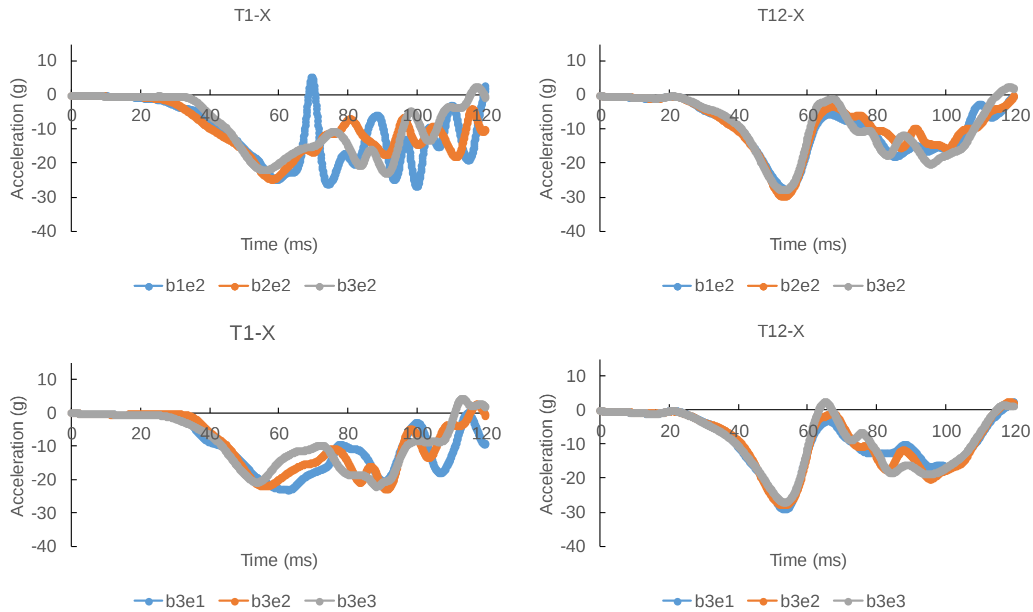

Fig 3. The chest accelerations in T1 and T12（fist row: influenced by seatbelt height, second row: influenced by seatbelt angle）

3.2 Chest deflection

This section is about the influence of seatbelt height (Fig 4) and seatbelt angle (Fig 5) on chest deflections. Compared with the seatbelt height, seatbelt angle influenced the chest injuries less. The LL will not change with the changing of the seatbelt angle. Maybe this indicted the seatbelt would not affect the compression caused by seatbelt loading. Regarding the measuring points along these seatbelt paths (UL and LR), when the seatbelt angle changed from level 2 to level 3, the changes of these points were not obvious. But when seatbelt angle changed from level 1 to level 2, the changes were significant which was a decrease in UL and an increase in LR. The change in UR was similar to LR, but fluctuated more.

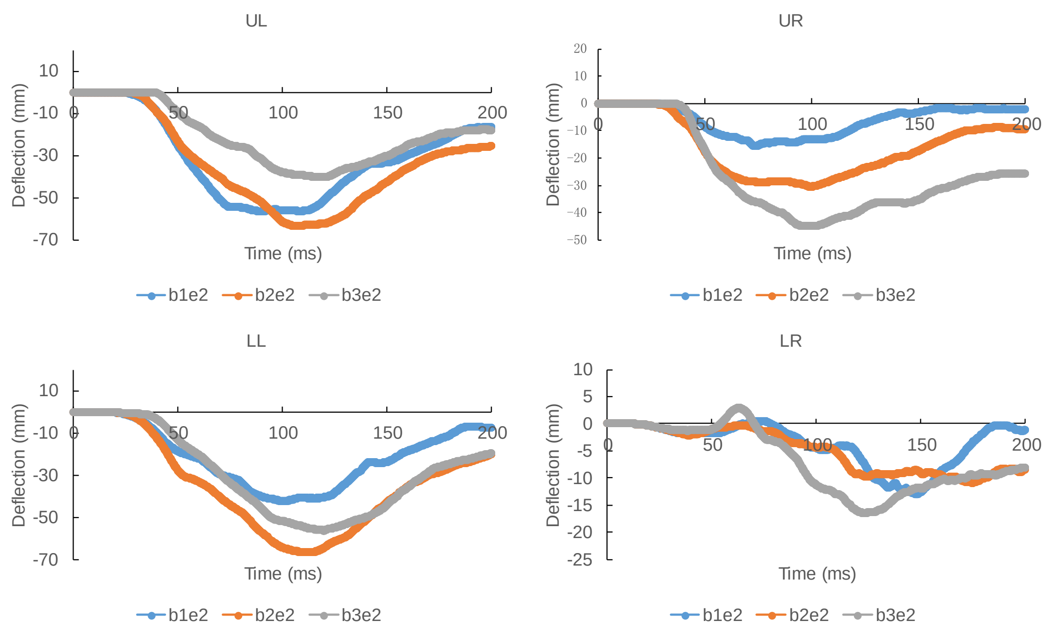

Fig 4. Chest deflections with the change of seatbelt height

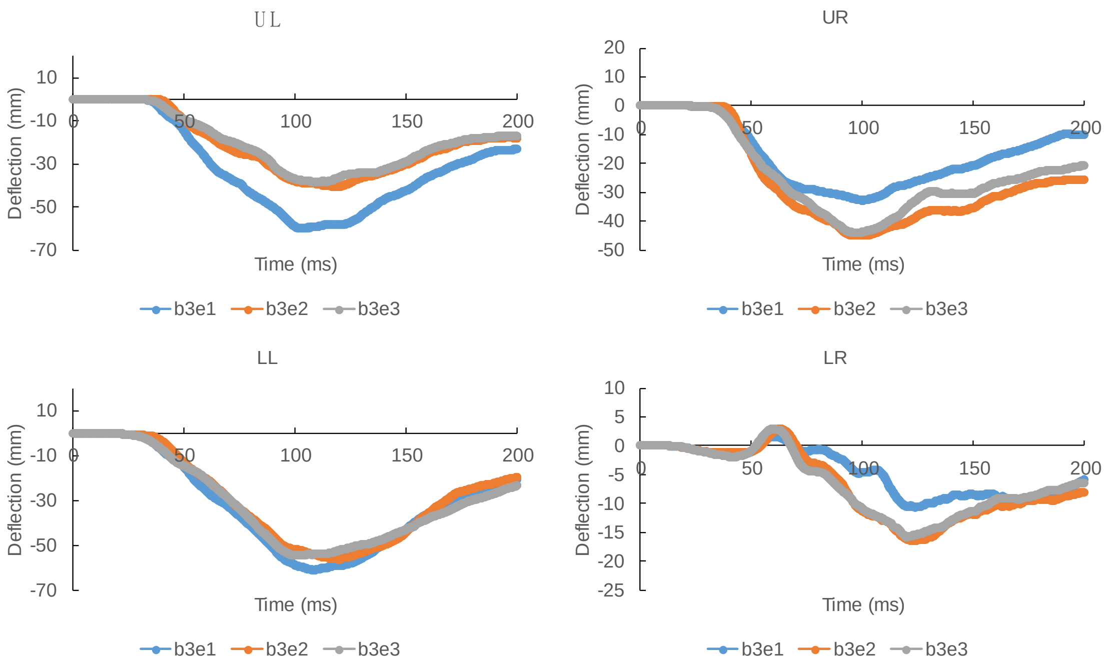

Fig 5. Chest deflections with the change of seatbelt height

Judging from the peak chest deflections, when the seatbelt angle changed, the deflection would not change much. There was a small change in the left ribcage. In contrast, the changes in right were small, and the changing trends were the same. UR and LL would increase with the increase of the seatbelt angle. Meanwhile, UL and LR would decrease with the decreasing of the seatbelt height. Most of the changes happened with the changing of the seatbelt height but not seatbelt angle.

4 Discussion

Seatbelt height is more important in the influence of chest injury response in all the four measuring points. The influence on LR is small because the relative distance between LR and seatbelt path is very large, which indicates the affection of the compression caused by seatbelt loading to this point is small. The correlations between the left two measuring points and seatbelt is nonlinear and linear for the right points.

The belted occupant model is sensitive to the seatbelt position parameters. Specifically, the chest deflection is more sensitive to seatbelt height than angle [5]. Meanwhile, the chest will not response similarly to the loadings from different positions. This is because different seatbelt paths can cause different chest deflection outcomes.

5 Conclusion

According to the sled test configuration, the belted occupant model was positioned on the test sled. The chest injury responses are then studied by adjusting the parameters of the seatbelt restraint system. The results show that the seatbelt height will highly affect the chest injury outcome compared with the seatbelt angle. The left chest is more sensitive to the change of both seatbelt height and angle. This study method can provide a reference to the improvement of restraint design.

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