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Soft Tissue Injury Risk in Chest and Abdomen of 3YO Child based on CRS dynamic load

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Abstract: The chest and abdomen soft tissue injury risk to three-year old (3YO) child occupant in a child restraint system (CRS) was investigated by using finite element (FE) simulation, based on the UN R129 dynamic test regulation. In which, Q3 dummy FE models and THUMS 3YO Occupant Model Academic Version 4 (THUMS 3YO) and two types of CRSs (impact shield and five-point harness) were used. The chest physical injury parameters, and the chest soft inner organs parameters were compared in two types of CRSs. The simulation result shows that significant difference of chest deformation observed in Q3 and THUMS 3YO. The stress and strain distribution of chest and abdomen visceral organs of THUMS 3YO in the two CRSs were larger than the injury threshold. Moreover, in the impact shield CRS, the distribution of the stress-strain and absolute value was larger, to predict a higher chest injury risk.

Keywords: child occupant; impact shield CRS; chest injuries; abdomen injuries

INTRODUCTION

In recent years, it has become a hot topic of concern to all sectors of society that frequent traffic accidents caused child casualties. A survey showed that the chest and abdomen injury up to 13%, second only to head and neck injury, is one of the important reasons for the death of children in a frontal collision [1].

Due to ethical restrictions, there are few studies on the internal organs of the chest of child occupants, and there is no relevant detailed regulations on child's chest damage threshold. As a pragmatic threshold, the Q3 chest deflection of 40 mm (monitored only) was proposed for amendments to R129 phase 1. Kroell et al. [2] have shown that it is more accurate to determine the AIS rating by using chest compression according to the vertebral acceleration or chest loading in the frontal crash experiment; Viano and Lau [3] found that when the chest compression ratio achieved 37.9%, the human body was predicted a 50 percentage of AIS4 injury risk.; Lau and Viano [4] first proposed viscous injury criteria from visceral absorption of adhesive performance in 1985, that is, the amount of chest deformation rate (V) and compression (C) predicts chest soft tissue injury in the high-speed collision. The formula is as follows: V(t)[m/s]——Obtained by differential of chest deformation D(t); C(t)——Instantaneous compression, that is, the ratio between the deformation D(t) and the initial chest thickness b, the damage tolerance limit value $VC_{max} \leqslant 1.0$ m / s;

$$VC = V(t) \times C(t) = \frac{d[D(t)]}{dt} \times \frac{D(t)}{b}$$

Based on the above research results, in order to understand the damage of thoracic and abdominal visceral soft tissue and organs of the 3YO child occupants, the finite element simulation method was used to predict the chest and abdomen injury by analyzing the force of the visceral soft tissue in the chest and abdomen in dynamic loading

FE simulation

In this paper, the Q3 dummy and THUMS 3YO finite element model were used to analyze the chest and abdomen injury risk of impact shield type CRS A and five-point harness CRS B. The simulation solver used LS-DYNA with a single-precision version 7.0. The THUMS 3YO finite element model was developed in 2016 by Toyota Motor Corporation and Toyota Central Research and Development Labs, which modeled the risk of injury to children's internal organs during dynamic loading (Fig. 2). Based on the UN R129 regulations, the CRS sled collision simulation model was established, in which the CRS geometric model was scanned by reverse engineering. The acceleration of the sled is shown in Fig. 3. Impact shield and five-point harness CRS simulations set-up is shown in Fig. 4.

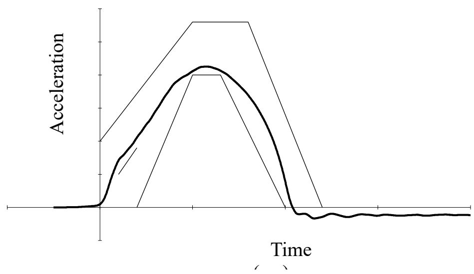


Fig. 3. Acceleration of the sled with UN R129 corridor.

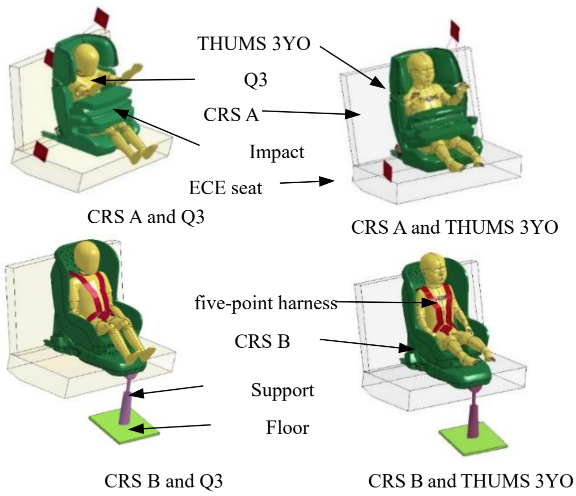


Fig.4. Impact shield and five-point harness CRS simulations set-up

Chest Injury Parameters

Fig. 7 and Fig. 8.shows the chest deflection and chest acceleration of the Q3 and THUMS 3YO in CRS A and CRS B. Q3 simulation curve are consistent with test basically in the pulse width, maximum, tangential slope, direction, etc. From the curve of Fig. 7 shown, the chest accumulated 3ms acceleration (402 m/s^2) of THUMS 3YO is larger than Q3 (372.7 m/s^2)and reaches a peak at about 95 ms, which is the result of the contact of the dummy's chin with the chest in combination with kinematics; The chest deflection of THUMS 3YO is 47.1mm(Table 1), about 1.5 times the Q3, and reached more lately than the Q3, which achieved AIS 4 injury risk according to the study of compression impairment criteria of Kroell.

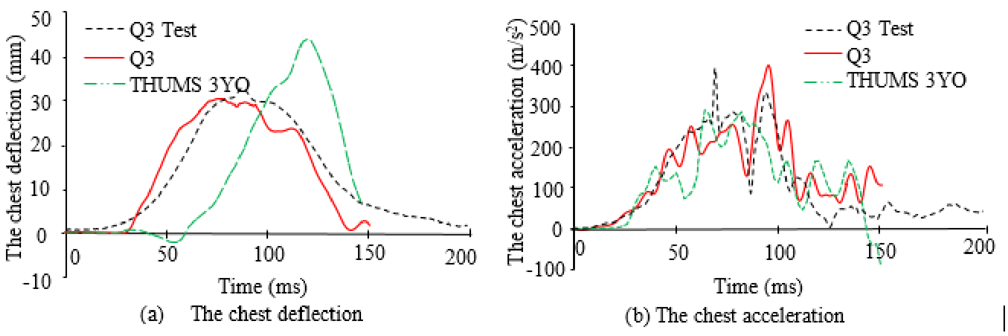
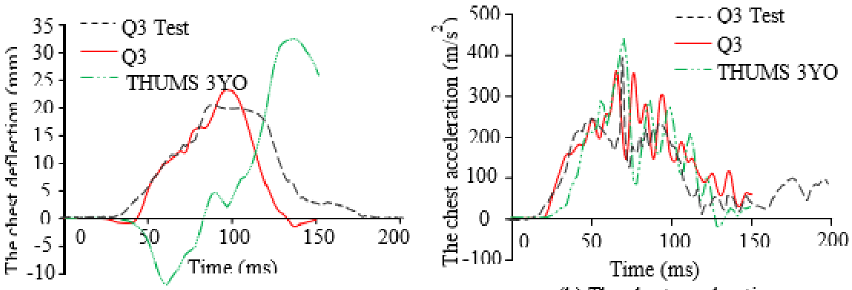


Fig. 7 the chest deflection and chest acceleration of the Q3 and THUMS 3YO in the impact shield CRS A

From the curve of Fig. 8 shown, The chest result acceleration of THUMS 3YO model is still high after reaching the peak, and Q3's chest result acceleration curve shows many peaks due to the contact between the five-point seatbelt and Q3 internal structure; THUMS 3YO has a chest compression of 34.8 mm below the threshold.



(a) The chest deflection (b) The chest acceleration

Fig. 8 the chest deflection and chest acceleration of the Q3 and THUMS 3YO in the impact shield CRS B

Table 1 Injury Criteria of Q3 and THUMS 3YO

CRS type	Simulation matrix	chest deflection	Compression ratio	chest acceleration (3 ms)
CRS A	Q3 Test	33.6 mm	28%	319.4 m/s2
	Q3	31.3 mm	26.08%	372.7 m/s2
	THUMS 3YO	47.1 mm	39.25%	299 m/s2
CRS B	Q3 Test	20.2 mm	16.83%	253.4 m/s2
	Q3	23.4 mm	19.5%	327.1 m/s2
	THUMS 3YO	34.8 mm	29%	410 m/s2

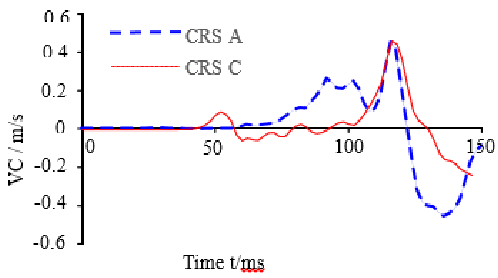


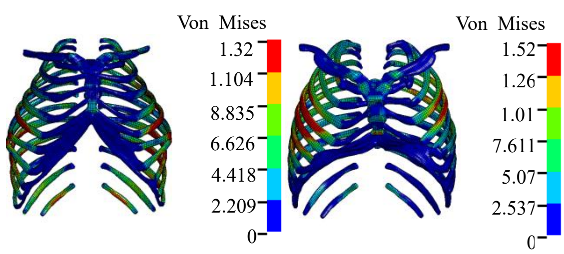
Fig. 9 the time course curve of VC

Fig. 9 shows the time course curve of Chest Viscosity Damage Criteria VC of the THUMS 3YO. According to Figure 9, the maximum VC of the two seats is less than 1.0 m / s, which predicts that the chest of child occupant does not occur viscous injury.

5. Stress and strain in internal organs of chest

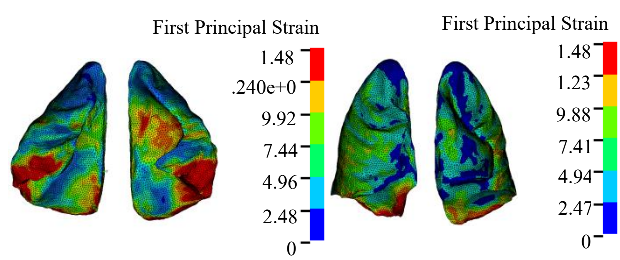
5.1 Ribs

The Von Mises Stress cloud of the ribs, sternum, and clavicle of THUMS 3YO in CRS A and CRS B is shown in Figure 10 (unit: MPa). Kemper et al. [5] obtained failure stress (130.8 MPa) by a three-point bending test on the 4th to 7th ribs of adults. It can be seen from the stress cloud diagram that the maximum Von Mises Stress is CRS A 132.5MPa and CRS B 152.2MPa respectively. The study shows that the thorax is soft and the ribs are not easy to fracture. The current stress changes can't predict whether the 3YO child will have rib fracture injury, but can analyze the force of the ribs in the CRS A is larger than CRS B.



(a) CRS A (b) CRS B

Fig 9 The Stress cloud of the ribs, sternum and



(a) CRS A (b) CRS B

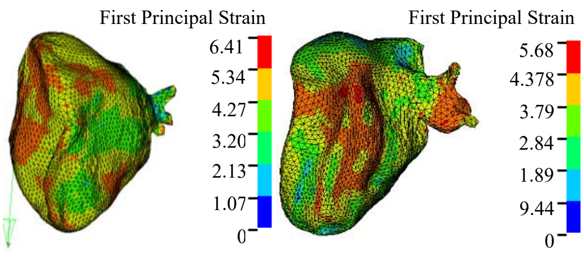
Figure 11 the first principal strain cloud of the lung tissue

5.2 Lung

GAYZIK et al. [6] used the animal (mouse) test CT scan and simulation to point out that the first principal strain can be used to predict lung injury better and the threshold of the first principal strain injury is about 35% in lung tissue injury in the finite element model. Figure 11 shows the first principal strain cloud of the lung tissue of THUMS 3YO in CRS A and CRS B. It can be seen from the strain cloud that the maximum first principal strain of lung tissue in CRS A and CRS B is 1.488 and 1.483, respectively, and the strain of CRS A is relatively large in the area, which can be predicted lung contusion could occur in the dynamic loading process.

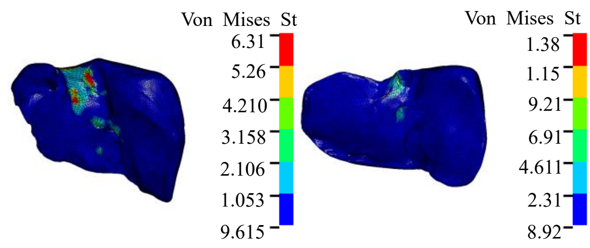
5.3 Heart

YAMADA et al [7] researched that the ultimate tensile strain of myocardial tissue of 0 to 9-year-old child is 62.9 ±6.9%, and the first principal strain tolerance limit of the heart contusion is 30% [8]. Figure 12 shows the first principal strain cloud of the heart of THUMS 3YO in CRS A and CRS B. It can be seen from the strain cloud that the maximum first principal strain of CRS A and CRS B is 64.18% and 56.86% respectively. The simulation results show that the child's heart in the two seats may be at risk of contusion in the dynamic loading process.



(a) CRS A (b) CRS B

Fig 12 the first principal strain cloud of the heart



(a) CRS A (b) CRS B

Fig 13 the Von Mises Stress cloud (unit: MPa) of the liver

5.4 Liver

2002 Tamura et al [9] researched that the maximum compressive stress interval of (pig) liver is 0.127-0.192 MPa through the experiment. Figure 13 shows the Von Mises Stress cloud (unit: MPa) of the liver in CRS A and CRS B for THUMS 3YO. The maximum Von Mises stress in the liver of CRS A and CRS B was 6.315MPa and 1.382MPa, respectively. It can be seen from the stress cloud diagram that the stress of very individual unit in the liver of CRS B is relatively large, and the maximum stress unit area in CRS A is relatively larger. Because Tamura draft the liver damage threshold through the pig test, it can't accurately predict the liver damage in the dynamic loading of the finite element, only predict that the risk of liver tear injury in CRS A is higher than that in CRS B.

Discussion

In the finite element simulations, the chest deflections of Q3 and THUMS 3YO were very different. Spine stiffness could be one of the more important factors that causes these differences. Q3's spine is defined as a rigid body, no deformation, so the pelvis will have a tendency to be ejected from the CRS in the rebound stage, and the moment of the rebound phase would be earlier than THUMS 3YO.

By analyzing stress and strain of the chest and abdomen organ of THUMS 3YO in the impact shield CRS A and five-point harness CRS B, the Von Mises stress of the ribs and the liver, as well as the first major strain of the lung tissue and the heart exceeds the damage limit, and compared the thoracic compression rate, it can be seen that squeeze injury risk is great in the chest and abdomen, but compared to VC value, the risk of viscous injury is almost non-existent. An important reason for the above-mentioned damage may be the biomechanical properties of the 3YO children, and these chest damage thresholds are obtained for adults or by animal experiments. The damage results can only provide a trend and can't be accurately predicted.

Conclusions

In this paper, the chest and abdomen injury risk to 3YO child occupant in the impact shield and five-point harness CRS was investigated by using FE simulation. The conclusions are summarized as follows: The significant difference of chest deformation observed in Q3 and THUMS 3YO. The chest deformation rate of THUMS 3YO FE model was 39.25% in the impact shield CRS, which predicted a 50 percentage of AIS injury risk; The stress and strain distribution of chest and abdomen visceral organs of THUMS 3YO in the two CRSs were larger than the injury threshold. Moreover, in the impact shield CRS, the distribution of the stress-strain and absolute value was larger than that in 5-point harness CRS, to predict a higher chest injury risk in impact shield CRS.

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