INJURY SIMULATION OF REAR SEAT CHILD OCCUPANT IN OFFSET DEFORMABLE BARRIER FRONTAL IMPACT

Tomoshi Takahashi
Satoshi Fukushima
Yuichi Kitagawa
Tsuyoshi Yasuki
Toyota Motor Corporation
Japan

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ABSTRACT

From 2016, Euro NCAP plans to assess child occupant protection performance with Q6 and Q10 dummies in a 64 km/h offset deformable barrier (ODB) frontal impact test. This paper describes research simulating this frontal impact test using a ten-year old (10YO) version of the Total Human Model for Safety (THUMS) and an FE model of the Q10 dummy. The changes in impact kinematics and injury values of the 10YO THUMS model were compared with the Q10 dummy under various load limiter (L/L) values ranging from 2 to 5 kN, and the differences between the two were examined.

Differences in the kinematics between the two mostly appeared during the second half of the test. As a result, the displacement of the head and chest of the Q10 dummy was smaller than that of the 10YO THUMS model. This result was probably because the thoracic plate of the Q10 dummy hindered the flexion of the thoracic spine. In addition, the chest upper deflection of the Q10 dummy resulted in higher injury values. This result was assumed to be because the shoulder belt was positioned close to the chest upper deflection gauge. In addition, the change in the chest upper deflection of the Q10 dummy was greater than that of the 10YO THUMS model, with a sensitivity of approximately four times as large. This result was due to the high force transmission ratio from the clavicle to the sternum.

INTRODUCTION

According to European accident statistics, the rate of child (0 to 14 year-old) occupant fatalities in the EU in 2009 amounted to 2.5 people in 100,000 (Kirk et al., 2012). As one measure to help improve the safety of child occupants, the EU enacted ECE R44 in 1981 to specify safety criteria for child seats. Euro NCAP then began assessing child occupant protection performance from 2003.

The development of the Q-series of child dummies began in 1993. Five completed dummies have already been completed, ranging in age from 0 to 6 years old, and the 10-year old Q10 dummy is due to be completed in the near future. Currently, Euro NCAP assesses child occupant protection performance using the 1.5-year old Q1.5 dummy and the 3-year old Q3 dummy. In addition, Euro NCAP has also announced plans to adopt the 6-year old Q6 dummy and the 10-year old Q10 dummy from 2016. Although various researches have examined the injury states, tolerances, and thresholds of child occupants, little information is available compared to research into adults. Physical tests on live subjects have been carried out at low force levels, assuming playground accidents. However, there is very little information related to tolerance and threshold at high forces such as in impact tests. For this reason, research using human finite element (FE) models is regarded as an effective means to better understand pediatric injuries.

The research described in this paper compared the occupant kinematics and injury values in a frontal impact using a ten-year old (10YO) version of the THUMS human FE model and an FE model of the Q10 dummy. Assuming the same conditions as the 64 km/h offset deformable barrier (ODB) frontal impact test used in Euro NCAP, the simulation placed the child occupant models in a junior seat (JRS) located in the rear. The impact kinematics and injury values of rear seat occupants are affected by the load limiter (L/L) device of the seatbelts. Therefore, this

research also examined changes in the displacement and injury value for each part of the occupant (i.e., the sensitivity) under various L/L values. After describing these simulations, this paper details the differences in impact kinematics and injury values of the 10YO THUMS and Q10 dummy models.

METHOD

The first section of this paper describes an outline of the FE models used in the research.

Vehicle FE Model

The simulated test vehicle was a B-segment compact car with a weight of 1,070 kg. The FE model of the test vehicle was created to represent its geometry and structure, including component parts. It was verified that the floor deceleration pulse, forward displacement, and yawing motion matched those measured in an ODB frontal impact test of this vehicle. The seatbelts in the rear seats for child occupants were equipped with a pretensioner to remove slack and an L/L function to control the occupant restraining force.

JRS FE Model

A high-backed JRS in the 2-3 weight group was used. The FE model was created using external geometrical data obtained using optical measurement. The plastic and metal parts were modeled with shell elements, while solid elements were used for the foam parts. The average mesh size was 5 mm. It was verified that the deformation stiffness and strength of the head and lateral supports were consistent with those of actual JRS.

10YO THUMS Model

The 10YO THUMS model was created by changing the 6YO THUMS pedestrian model created by Nishimura et al. (2002) to a seated posture and scaling up the physique to that of a 10-year old child. The seated height of the 10YO THUMS model was changed to match that of the Q10 dummy. Both models had a weight of 35 kg. The impact response of the 10YO THUMS head was previously verified by Nishimura et al.(2002), while the chest response was verified in the research by comparison with the chest loading tests on post mortem human subjects (PMHS) of a 10-year old (Kent et al., 2012). The head displacement was measured at the center of gravity of the head and the chest displacement was measured at the fourth thoracic vertebra (T4). The displacement data was transferred to the vehicle (the rear floor) coordinate system. The upper and lower chest deflections were calculated in accordance with the measuring points on the Q10 dummy.

Q10 Dummy FE Model

The Ver. 1.2.1 Q10 dummy FE model (Humanetics Innovative Solutions, Inc. ,2013) was used for the comparison with the 10YO THUMS model. The head and chest response were verified based on the details of Humanetics Technical Reports. The displacement and injury values of each part were outputted following the Humanetics User Manual from the sensors set inside the model. The displacement data was transferred to the vehicle coordinate system as processed in the 10YO THUMS model.

Calculation Model and Conditions

The JRS model was placed on the right rear seat (i.e., the far side of the vehicle) assuming fixation through the ISOFIX anchors. Both the 10YO THUMS and Q10 dummy occupant models were seated so that their backs were in contact with the seatbacks. The seatbelts were wrapped around the torsos of the dummies passing through the belt guides. The pretensioner was activated at 20 msec after the impact, based on the specifications of the tested vehicle. Eight cases were simulated with the 10YO THUMS and Q10 dummy models, changing the L/L value from 2 to 5 kN. The kinematics of each part of the models and the injury values were compared for each case. Table 1 shows the calculation conditions for all eight cases.

Table 1. **Simulation Matrix**

CASE		1	2	3	4	5	6	7	8
Test Condition		64kph ODB				64kph ODB			
Vehicle Type		Compact Car				Compact Car			
Occupant Position		Rear Seat (Far Side)				Rear Seat (Far Side)			
Child Occupant Model		**10YO THUMS**				**Q10 dummy**			
JRS	Seat Back	Available				Available			
	Mount	ISO-FIX				ISO-FIX			
Seatbelt	P/T	Available				Available			
	L/L	2kN	3kN	4kN	5kN	2kN	3kN	4kN	5kN

RESULTS

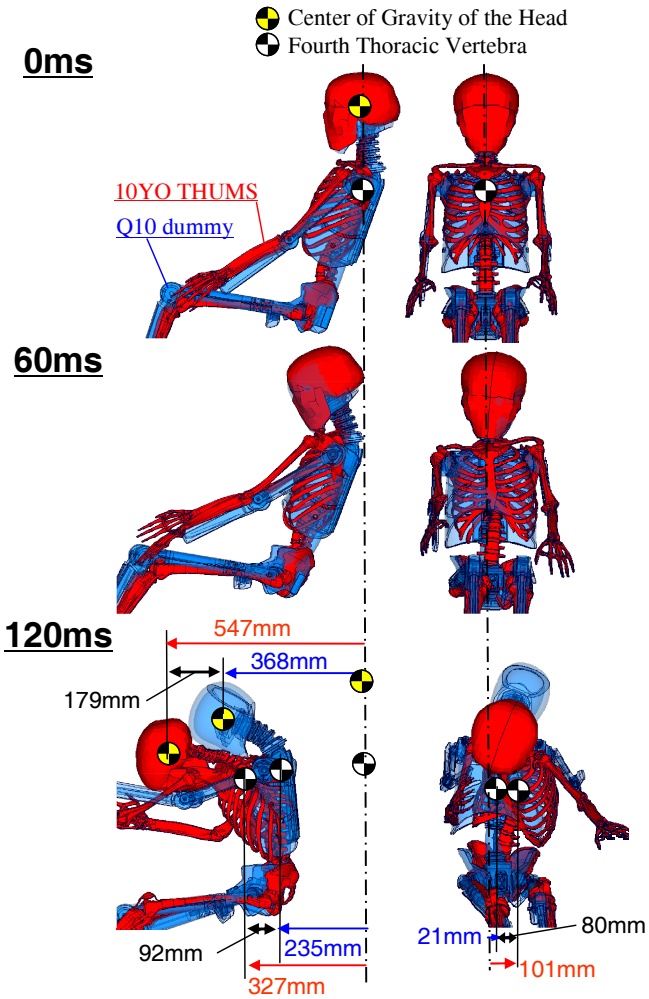
This section compares the impact responses and injury values of the 10YO THUMS and Q10 dummy models between cases 3 and 7 (L/L value: 4 kN).

Kinematics

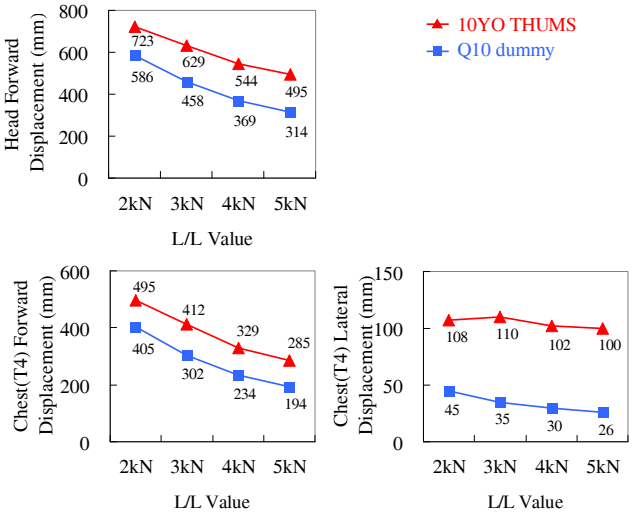
Figure 1(a) superimposes the kinematics of the 10YO THUMS and Q10 dummy models at 0, 60 and 120 msec after the impact. In both models, the upper body flexed after the pelvis stopped. The head positions of two models were almost identical up to 60 msec but diverged after that. The upper body flexion and lateral bending of spine were greater in the 10YO THUMS model than those in the Q10 dummy. At 120 msec, the head forward displacement of the 10YO THUMS model was 547 mm and the chest (T4) forward displacement was 327 mm. These values were 179 mm (head) and 92 mm (chest) larger than those of the Q10 dummy, respectively. The lateral displacement of the 10YO THUMS model (chest) was 101 mm, larger than the 80 mm recorded by the Q10 dummy.

Figure 1(b) shows the changes in the maximum forward displacement of the head and chest under different L/L values. The maximum lateral displacement of the chest is also shown. Under the same L/L value, the 10YO THUMS model exhibited greater displacement than the Q10 dummy. The maximum forward displacement increased as the L/L value decreased. In contrast, there was little difference in the sensitivity of the maximum forward displacement against the L/L value. Under the impact conditions assumed in the research, the head of the 10YO THUMS model contacted the back of the front seat in case 1 (L/L value = 2 kN).

The maximum lateral displacement of the chest in the 10YO THUMS model was larger than that in the Q10 dummy. In this model, the lateral displacement increased as the L/L value decreased. However, in case 1 only, the lateral displacement of the 10YO THUMS model was smaller than that in case 2 even though the L/L value was smaller.



(a) Comparison of 10YO THUMS and Q10 dummy models (cases 3 and 7)



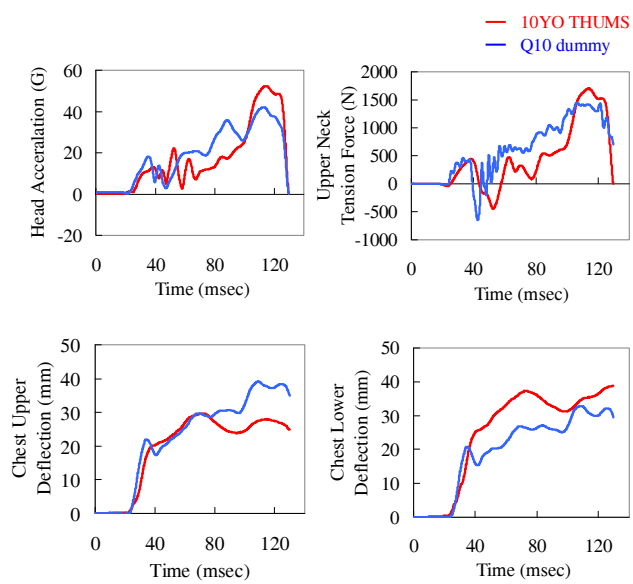
(b) Maximum displacement of head and chest at each L/L value

Figure 1. Occupant displacement and sensitivity of displacement of each part to L/L value.

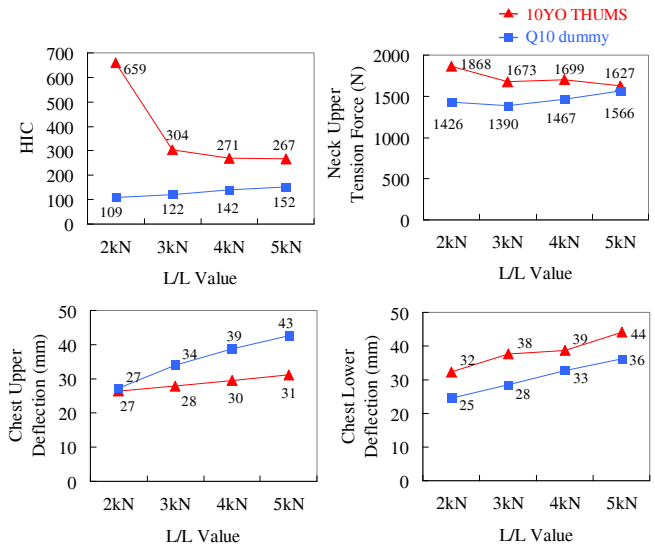
Injury Values

Figure 2(a) compares the time history curves of the head resultant acceleration, upper neck tension force, and chest deflections (upper and lower) of the 10YO THUMS and Q10 dummy models. The head resultant acceleration and upper neck tension force reached the maximum peaks at 116 msec, which was close to the timing of the maximum head forward displacement (120 msec). It should be noted that the maximum values in all cases were higher for the 10YO THUMS model. The chin and clavicle of the Q10 dummy came into contact at 85 msec, generating an initial peak for head resultant acceleration. Initial peaks for the chest upper and lower deflections appeared at 76 msec and the maximum values appeared after 116 msec. At 76 msec, the shoulder belt restrained the Q10 dummy from the chest to the abdomen. At 116 msec, the upper body flexed, causing the clavicle to be restrained by the shoulder belt. Although the maximum chest upper deflection of the 10YO THUMS model was smaller than that of the Q10 dummy, the chest lower deflection was greater.

Figure 2(b) shows the relationship between the L/L value and the head injury criteria (HIC), as well as the injury values for the neck (upper neck force) and chest (chest upper and lower deflections). Apart from the chest upper deflection, the injury values of the 10YO THUMS model were higher in all cases than the Q10 dummy. In the 10YO THUMS model, the HIC increased as the L/L value decreased. In contrast, the HIC of the Q10 dummy decreased as the L/L value decreased. The HIC was particularly high in case 1, in which the head contacted the back of the front seat. Although the upper neck force of the 10YO THUMS model increased as the L/L value decreased, the upper neck force of the Q10 dummy model decreased under the same conditions. The chest upper and lower chest deflection of both the 10YO THUMS and Q10 dummy models also decreased as the L/L value decreased. However, the change in the chest upper deflection of the Q10 dummy was greater than in the 10YO THUMS model, with a sensitivity of approximately four times as high.



(a) Time history comparison of head resultant acceleration, upper neck tension force, and chest deflection (cases 3 and 7)



(b) Injury values of each part at each L/L value

Figure 2. Injury value time history and sensitivity of displacement of each part to L/L value.

DISCUSSIONS

Cause of Smaller Head and Chest Displacement in Q10 Dummy Compared to 10YO THUMS Model

The mass distribution, dimensions and stiffness of body parts of the Q10 dummy closely match the average values of a 10-year old (Lemmen et al., 2012). However, the Q10 dummy has a rigid block, called a thoracic plate, for supporting the measurement instrumentation. The flexion range of the thoracic spine was relatively small due to the higher rigidity of this part compared to an actual human spine.

The smaller forward displacement of the Q10 dummy head compared to the 10YO THUMS head was analyzed comparing cases 3 and 7. The head forward displacement is mostly determined by the pelvis displacement and the flexion of the cervical, thoracic, and lumbar spines. Figure 3 compares the contributions of pelvis displacement and spine flexions between the 10YO THUMS and Q10 dummy. In the 10YO THUMS model, 328 mm (60%) of the head displacement amount of 544 mm was caused by the flexion of the thoracic spine. In contrast, the Q10 dummy had little flexion of the thoracic spine. This suggests that the thoracic plate of the Q10 dummy hindered the flexion of the thoracic spine. The rigidity of the thoracic plate was also a possible factor of the smaller chest forward displacement of the Q10 dummy.

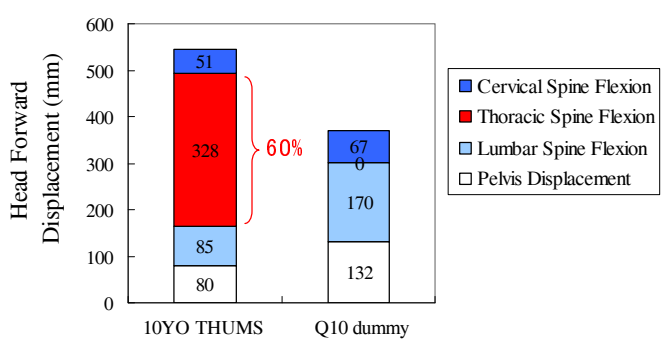


Figure 3. Contributions of pelvis displacement and spine flexions to head forward displacement.

Cause of Higher Chest Deflection in Q10 Dummy Compared to 10YO THUMS Model

The contact force of the shoulder belt acting on the chest of the Q10 dummy (6,500 N, case 7) was lower than that of the 10YO THUMS model (8,300 N, case 3). Lemmen et al. (2012) reported that the chest deflection responses of the Q10 dummy are within the test corridor. These points indicate that the cause of the difference in chest deflection is neither the force of the shoulder belt nor the chest deflection responses of the Q10 dummy. This research focused on the relationship between the chest deflection measurement points and the position of the shoulder belt.
Figure 4 shows the positional relationship at the maximum chest deflection. The distance between the chest upper deflection measurement point and the center of the shoulder belt in the width direction was 89 mm in the 10YO THUMS model (case 3). This differed greatly from the distance in the Q10 dummy, which was only 7 mm (case 7). The shoulder belt contacted the area around the chest upper deflection measurement point in the Q10 dummy, while the belt was at the lower area in the 10YO THUMS model. This is thought to be the reason why the chest upper deflection of the Q10 dummy was greater than that of the 10YO THUMS model.

As shown in Figure 1(a), the Q10 dummy model exhibited much smaller chest lateral displacement (21 mm at 120 msec) compared to the 10YO THUMS model (101 mm), while there was little difference in the chest vertical displacement. The shoulder belt kept in contact with the area around chest upper deflection measurement point in the Q10 dummy while the chest upper deflection measurement point deviated from the shoulder belt contact in the 10YO THUMS model.

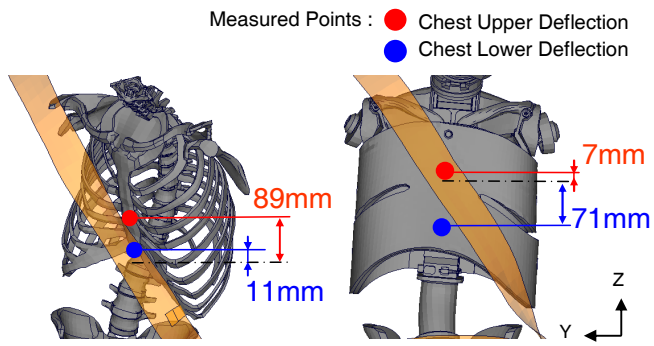


Figure 4. Positional relationship between chest and shoulder belt.

Cause of Higher Chest Upper Deflection Sensitivity to Changes in L/L value in Q10 Dummy

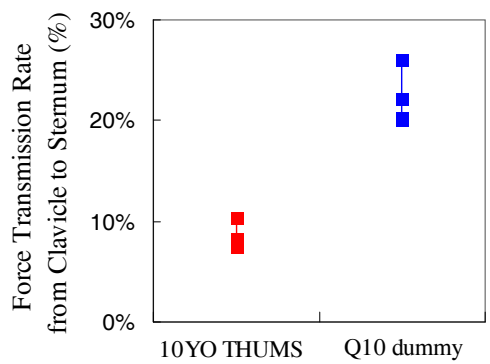
In the 10YO THUMS model, the chest upper deflection decreased by 5.3 mm for each 1 kN of the L/L value. However, in the Q10 dummy, the chest upper deflection decreased by only 1.3 mm. The sensitivity of the chest upper deflection to the L/L value was roughly four times higher for the Q10 dummy than the 10YO THUMS model.

In cases 3 and 7, the shoulder belt contact area was divided into three regions (the clavicle, chest, and abdomen) for analyzing the force contribution to chest deflection. The clavicle region covers the right shoulder and the right rib 1, the chest region covered the area from the right rib 2 to the left rib 9, and the abdominal region covered the area below the left rib 9. At the maximum chest upper deflection, 48% of the force was generated at the clavicle region, 37% at the chest region, and 15% at the abdominal region. Of these, the forces at the clavicle and abdominal regions do not directly cause an increase in upper chest deflection. There were little differences in the change in clavicle force between both models with different L/L values.

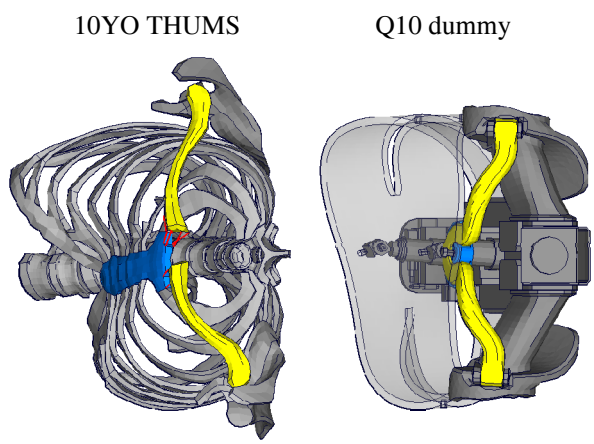
The ratio of force transmission from the clavicle to the sternum (force transmission rate) was compared between the 10YO THUMS and Q10 dummy models. This ratio was 22% in the Q10 dummy but only 8% in the 10YO THUMS model, approximately 2.6 times higher (Figure 5(a)) than the rate for the Q10 dummy. In the human body, the left and right clavicles are completely separate and join to the sternum through ligaments. On the other hand, the clavicle

of the Q10 dummy is a single part extending laterally from the left to the right and bolted to the ribcage (Figure 5(b)). The high sensitivity of the chest upper deflection of the Q10 dummy is due to the smaller freedom of deformation of the joint between the clavicle and sternum, which facilitates transmission of the shoulder belt load acting on the clavicle to the sternum.

It is considered that the impact kinematics and responses of the Q10 dummy could be made closer to those of the 10YO THUMS model by improving the flexibility of the thoracic spine and the joint between the clavicle and sternum.



(a) Force transmission rate from clavicle to sternum



(b) Deformation of clavicle and sternum with fixed spine (116 msec)

Figure 5. Clavicle force transmission rate and structural differences.

Limitation

This research was conducted assuming particular impact conditions (vehicle, impact pattern, and speed). The investigation does not comprehensively cover all the types of accidents that occur in the real world and is not directly related to accident results.

CONCLUSIONS

This paper described a simulated 64 km/h ODB frontal impact test using 10YO THUMS and Q10 dummy models. The changes in impact kinematics and injury values of the two models were compared under various L/L values ranging from 2 to 5 kN.

The kinematics of the 10YO THUMS and Q10 dummy models were almost identical up to 60 msec after the impact. However, the forward and lateral displacements of the 10YO THUMS model were larger than those of the Q10 dummy after 60 msec. The Q10 dummy exhibited lower head resultant acceleration, smaller upper neck tension force, greater chest upper deflection, and smaller chest lower deflection. The changes in the injury values under different L/L values were similar between the 10YO THUMS and Q10 dummy models. However, the change in the chest upper deflection of the Q10 dummy was greater than that of the 10YO THUMS model, with a sensitivity of approximately four times as high.

The smaller head and chest displacement in the Q10 dummy compared to the 10YO THUMS model was probably due to the thoracic plate of the Q10 dummy hindering the flexion of the thoracic spine. The greater chest upper deflection of the Q10 dummy was assumed to be because the shoulder belt was positioned close to the chest upper deflection gauge. The high sensitivity of the chest upper deflection of the Q10 dummy to the L/L changes was probably due to the high force transmission ratio from the clavicle to the sternum.

These results showed that the impact kinematics and responses of the Q10 dummy could be made closer to those of the 10YO THUMS model by improving the flexibility of the thoracic spine and the joint between the clavicle and sternum.

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