A Study of Side Airbag Effectiveness in Reducing Chest Injury in Car to Car Side Impacts Using a Human FE Model

Shigeki Hayashi[1], Tsuyoshi Yasuki[1]
Yasuo Yamamae[2], Yoshiki Takahira[2]
[1]Toyota Motor Corporation, [2]Toyota Technical Development Corporation

Abstract

The effect of side airbag in reducing chest injury in car-to-car side impacts was studied using a human FE model (THUMS). A simulation was conducted assuming that a car was struck by another car at 50 km/h impact speed. Injuries were predicted for both front and rear seat occupants, and compared between cases with and without side airbags. Rib fractures were observed in the inferior thorax regardless of seating position without side air bags. With side air bags, on the other hand, the number of rib fractures was reduced because of smaller local deformation. The study also compares responses between the THUMS and the Euro-SID2 dummy model.

Key Words: SIDE IMPACT, SIDE AIRBAG, Human FE Model, EURO-SID2

In side collisions, the chest is considered one of the areas of a passenger's body most susceptible to injury. Side airbags have lately come to be equipped in cars as a safety device for protecting the passenger's chest. However, there is relatively little evidence in the literature to assess the effectiveness of side airbags because of limited data from accidents with their deployment (Morris et al. 2005, Yoganandan et al. 2005). In addition, many sled tests and thoracic impact tests have been performed using post mortem human surrogates (PMHS)(Cavanaugh et al., 1993, Chung et al., 1999), but there were few examples of published tests investigating the effectiveness of side airbags in simulated car-to-car side collisions within the authors' limited knowledge. Although side airbags should be effective in mitigating the impact severity to the occupant, there is discussion as to whether they might increase thorax deflection by filling out the space between the occupant body and the door inner panel. For this study, therefore, car-to-car side collisions were simulated with human FE models in cars equipped with side airbags in order to investigate the effectiveness of side airbags in reducing thoracic injuries.

Methods

The explicit FE code LS-DYNA Ver.970 was used in the simulated collisions. As for the car model, in addition to the main framework of the vehicle body, interior parts such as the seats and trim, as well as restraint devices like seat belts and side airbags were represented. The THUMS body type representing the car occupants approximated a 50th percentile American male (height 175cm, weight 77kg); Iwamoto et al. (2002) have reported that the dynamic response to impact input corresponds to the corridor of PMHS experiments written up in several research papers. This model can predict bony fracture by eliminating elements when strain levels exceed a specified value.

On the other hand, the Euro-SID2 (ES2) dummy model used for comparison was a modified base model commercially available from DYNAmore, and its dynamic response to impact input has been ascertained to be in agreement with the corridor of the dummy calibration tests. In order to verify the validity of the computation model, an experiment was carried out in which a moving barrier was made to collide with the side of a car, and the results were compared with an experiment which examined the deformation of the car body and the ES2 dummy response. As Figure 1 shows, the deformation of the car model was close to that found in the test car, and was mostly in agreement with time history for chest deflection and the abdominal load of an ES2 dummy (the rise timing and maximum value of the waveform). Next, a car-to-car side collision was simulated using the verified car model with THUMS seated in it. The striking car had a speed of 50km/h, with the center of the striking car impacted 250mm behind the seating reference point of the struck car (Figure 2).

THUMS models were placed in both front and rear seats using the standard seating position. Thorax airbags that would deploy from the seats for chest protection and a curtain shield type airbag that would deploy from the roof side rails for head protection were also introduced in the car model as shown in Figure3. Simulation was conducted for four cases in all, with and without airbags, and the results for the THUMS and ES2 were examined.

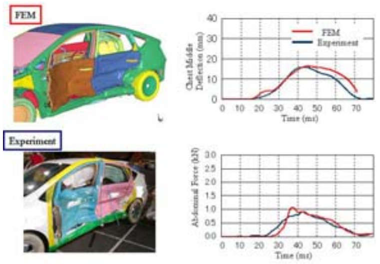

Figure 1. Validation of the car and dummy models

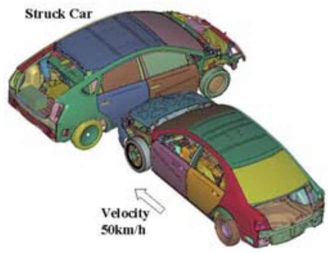

Figure 2. Car-to-car side collision model

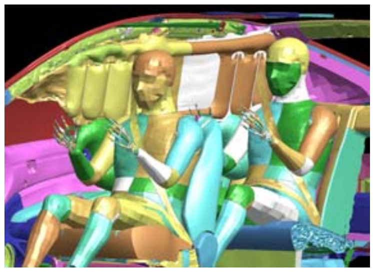

Figure 3. THUMS and interior parts

Results

The simulation results are summarized in Table 1. It shows the deflection value for each rib in the THUMS model. The amount of shortening in the distance from a node on the most outboard side of a rib to the spine was measured for each rib deflection. For ES2 dummies, the general measurements for rib deflection and abdominal force are described in Table2. In the four cases, irrespective of the presence or absence of side airbags, both THUMS and ES2 dummies had rib deflection and chest deflection of less than 42mm, which indicates resistance to the injury. For THUMS, when there were no side airbags, rib fractures in the inferior thorax were observed in both front and rear seats (Figure 4). It was found that in places where there were rib fractures, there had been an impact with the door arm rests. Rib fracture was also observed in THUMS front where the third rib intersects with the arm. On the other hand, computation results showed that in cases where side airbags are deployed, THUMS in the front seat would have fewer rib fractures and THUMS in the rear seat have no rib fractures. From these results, it appears that side airbags reduce the risk of rib fractures.

Table 1. Simulation Results: THUMS

Front Seat Occupant				Rear Seat Occupant			
With Side Airbag		W/O Side Airbag		With Side Airbag		W/O Side Airbag	
Single fracture at the middle of R-11th rib. (struck side)		Single fractures at the Middle of 3rd, 10th, 11th rib. (struck side)		No fracture.		Single fractures at the Middle of 4th, 10th rib. (struck)	
Rib Deflection				Rib Deflection			
Rib 4	4mm	Rib 4	4mm	Rib 4	15mm	Rib 4	17mm
Rib 6	7mm	Rib 6	0mm	Rib 6	15mm	Rib 6	11mm
Rib 8	10mm	Rib 8	1mm	Rib 8	8mm	Rib 8	13mm
Rib10	24mm	Rib10	19mm	Rib10	28mm	Rib10	30mm

Table 2. Simulation Results: ES2 dummy

Front Seat Occupant				Rear Seat Occupant			
With Side Airbag		W/O Side Airbag		With Side Airbag		W/O Side Airbag	
Chest Deflection				Chest Deflection			
Upper	13mm	Upper	11mm	Upper	17mm	Upper	21mm
Middle	13mm	Middle	5mm	Middle	13mm	Middle	11mm
Lower	17mm	Lower	6mm	Lower	13mm	Lower	8mm
Abdominal force				Abdominal force			
1.0kN		1.1kN		0.8kN		0.9kN	

In comparison with ES2 dummies, THUMS had relatively greater rib deflection in the inferior thorax, but that, in contrast, ES2 dummies experienced greater chest deflection in the superior thorax. It is impossible to measure chest deflection in the inferior thorax of ES2 dummies, but the value for abdominal force was less than 2.5kN, which indicates resistance to the injury.

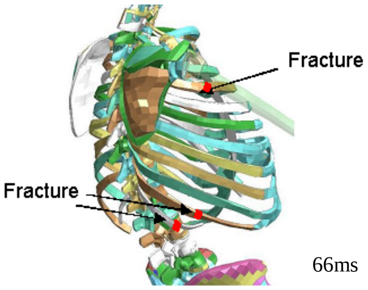

Figure 4. Rib fractures in cases without side airbags (THUMS in front seat)

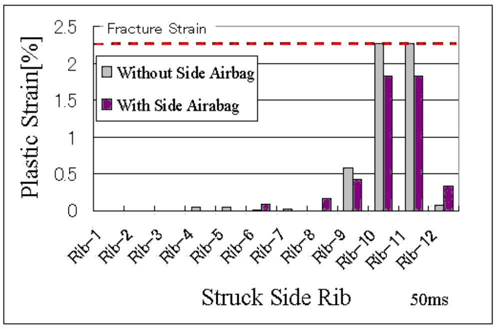

Figure 5. Distribution of plastic strain in ribs of dummy on the struck side of the car (THUMS in front seat)

Discussion

Side airbag effectiveness in reducing injury:

Figure 5 compares plastic strain distribution in the ribs of the chest in THUMS, for cases with and without side airbags. Because side airbags make contact with the chest over a wide area, the strain in the ribs is more distributed than when side airbags are not deployed, and there is a reduction in the highest figure for strain. Figure 6 shows the state of deformation of the ribs and thoracic vertebra 10-12. The simulation results show that, although when side airbags are present, there tends to be a slight increase in the deformation of the entire chest because the chest is pushed in the opposite direction from the impact, as this promotes a shift in the position of the spine, it has the effect of suppressing an increase in local deformation of the ribs. Furthermore, when comparing the load put on the arms by the door trim with and without side airbags, it was about 4kN without side airbags, whereas when the side airbags were deployed, it remained at about 2kN (Figure 7). A load value of 4kN is more or less in agreement with the resistance to rib fracture for an impact with an arm interposed, as reported by Cesari and others (1981). In other words, it has been observed that when side airbags are deployed, fracture in the superior thorax is avoided because the loading of the arm is decreased.

The difference between THUMS and ES2 dummy:

There was greater rib deflection in the inferior thorax than in the superior thorax for THUMS, but a tendency was seen for chest deflection to be greater in the superior thorax than in the inferior thorax of ES2 dummies. The chest of THUMS and ES2 dummy configurations were compared when their hips contacted the door trim and were displaced away to the inner side of the car (Figure 8). The chest of the THUMS remained upright, while the inferior thorax of the ES2 dummy was also displaced away to the inner side of the car. In other words, it is thought that the differences in the generation pattern of chest deflection arose because in THUMS, the load arising from contact with the door trim can be transmitted to the inferior ribs, while in ES2 dummies, the load arising from contact with the door trim is transmitted to the pelvis and the superior ribs. The fact that the chest of the THUMS has become upright while the pelvis is displaced indicates flexibility in the lateral bending and shearing of the human spine. The fact that such a phenomenon is not seen in ES2 dummies suggests the necessity of changing the characteristics of the dummy's lumbar parts in accordance with the measurement of deflection in the inferior thorax.

It should be noted that the study had limitations because it assumed a single condition for the vehicles, impact speed, impact direction, occupant size and seating position.

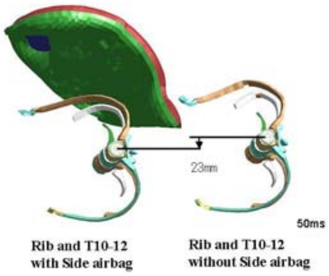

Figure 6. Comparison of lower thorax deformation with and without side airbags
(THUMS in front seat)

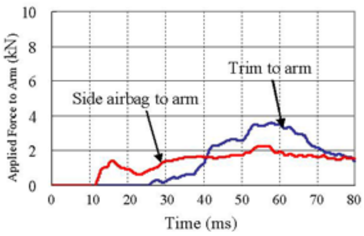

Figure 7.Comparison of the input load on arms, with and without side airbags
(THUMS in front seat)

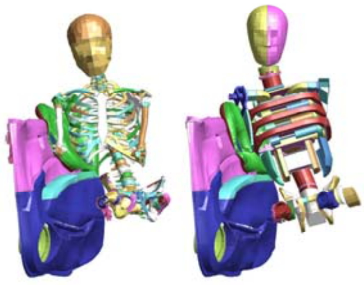

Figure 8. Comparison of THUMS and ES2 dummy behavior (In front seat@50ms)

Conclusions

Effectiveness of side airbags in reducing chest injury was examined with a human FE model THUMS subjected to car-to-car side collisions. Comparisons between the THUMS and the ES2 dummy, with and without airbags, revealed the following conclusions:

1. Although the computation results for THUMS predicted rib fracturing for both the front and rear seats when there were no side airbags, when side airbags were deployed, the risk of fracture was reduced.
2. It is thought that, because they make contact over a wide area of the chest, side airbags are effective in reducing the risk of rib fracture, especially in the inferior thorax, due to such effects as the distribution of the strain on individual ribs, promoting the shifting of the spine, and suppressing local deformation of the ribs.
3. It is thought that even when the arm is interposed between the ribs and the door, the load-diffusing effect of side airbags can lower the risk of rib fracture. (This is particularly effective in the superior thorax).
4. Since the lumbar spine of THUMS is flexible, so that the thorax can remain upright even if the pelvis moves, there is more deflection in the inferior thorax. In ES2 dummies, since the inferior thorax also moves when the pelvis does, there is more deflection in the superior thorax.

Acknowledgment

We acknowledge Dr. Yuichi Kitagawa of Toyota Motor Corporation for his technical advice. We wish to thank Shigeki Kojima, Naoko Kokubo of Toyota Technical Development Corporation and many who helped with the modeling and data analysis.

References

Cavanaugh J., Zhu Y., Huang Y., King A.,: Injury and response of the thorax in side impact cadaveric tests, 37th Stapp Car Crash Conference (1993), pp.199-221

Cesari D., Ramet M., and Bloch J.: Influence of arm position on thoracic injuries in side impact, 25th Stapp Car Crash Conference (1981), pp.893-919

Chung J., Cavanaugh J., King A., Koh S., Deng Y.: Thoracic injury mechanisms and biomechanical responses in lateral velocity pulse impacts, 43th Stapp Car Crash Conference (1999), pp.39-54

Iwamoto M., Kisanuki Y., Watanabe I., Furusu K., Miki K., Hasegawa J.: Development of a finite element model of the total human model for safety (THUMS) and application to injury reconstruction, IRCOBI (2002), pp.31-42

Morris A., Welsh R., Thomas P., and Kirk A.: Head and chest injury outcomes in struck-side crashes, IRCOBI (2005), pp.73-83

Yoganandan N., Pintar F., Gennarelli T.: Evaluation of side impact injuries in vehicles equipped with side airbags, IRCOBI (2005), pp.97-108