EVALUATION OF HYBRID III THORACIC INJURY CRITERIA IN IMPACTS WITH A SIMULATED TRUCK STEERING WHEEL – SUGGESTIONS FOR MODIFICATIONS IN INSTRUMENTATION AND REFERENCE VALUES

Kristian Holmqvist[1], Mats Y. Svensson[1], Johan Davidsson[1], Stefan Thorn[2]
[1]Chalmers University of Technology, SAFER Vehicle and Traffic Safety Centre and the Dept of Applied Mechanics, Vehicle Safety Division, SE-412 96 Göteborg, Sweden
[2]Volvo Technology Corporation, Department of Humans, Systems & Structures, SE-405 08 Göteborg, Sweden

ABSTRACT

Unbelted drivers of heavy commercial vehicles are likely to suffer chest injuries from steering wheel rim contact in frontal impacts. The aim of the present study was to investigate to what extent the current regulatory dummy, the Hybrid III, is capable of assessing the chest deflection in this load case. A Finite Element model of the dummy and its default sensors were evaluated together with chest injury criteria. The THUMS was used as a reference representing the human body. Suggestions on instrumentation and correction factors for injury criteria are proposed for use with the Hybrid III.

Keywords: Finite element method, Frontal impacts, Hybrid III, Thorax, Truck

IN HEAVY COMMERCIAL VEHICLES, low safety belt usage among drivers has been reported (Nyman et al., 2005) which is believed to increase the risk of steering wheel rim to chest contact in frontal collisions. The crash test dummy used in heavy commercial vehicle safety today is the Hybrid III dummy. This dummy is the only dummy used in legislative and consumer rating tests for passenger cars in frontal crash tests. As the dummy was developed for use in passenger cars, its suitability for use in heavy commercial vehicles was questioned. The objective of the studies presented here was to investigate the suitability of the Hybrid III dummy and its standard instrumentation in assessing chest injury risk in steering wheel rim to chest loading at different heights for drivers of large trucks. The injury criteria reference values were to be evaluated and if applicable, modified to better predict injury risk in this load case.

METHODOLOGY

Fiftieth percentile Finite Element (FE) models of the Hybrid III and THUMS (Total HUman Model for Safety, version 3.0, Toyota Central R&D Lab., inc.) was used to investigate the response and injury prediction capability of the dummy chest subjected to steering wheel rim impacts at different locations of the chest. The THUMS chest has a human-like geometry and has been validated for hub-type impacts (Iwamoto et al., 2002). Two-types of pendulum models were implemented, one of hub-type, a circular disc designed to mimic the impactor used by Kroell et al. in 1971, and one of bar-type (similar to the impactor used by Cavanaugh et al. 1986) to mimic the rim of a truck steering wheel (Figure 1). The bar-type impactor was identical to the hub-type impactor with respect to mass (23.1 kg) and impact velocity (6.7 m/s and 4.3 m/s). A twofold approach was used: firstly, the operation of the current deflection sensor in the Hybrid III chest was investigated. This was carried out to find out if additional sensors are needed to monitor the chest response accurately. Consequently, the chest was loaded using these two impactors at different heights, aimed at the middle of each of the six ribs (Figure 1) of the Hybrid III at a velocity of 6.7 m/s, resulting in a total of 12 impact conditions. Secondly, the THUMS and the Hybrid III model were exposed to identical simulated situations where the chest was struck at three locations, designated as higher, middle and lower. The location designated as middle is, in the Hybrid III, centered in the midsagittal plane of the chest located between rib three and four, commonly used for the calibration pendulum. For the human body model the middle location is the fourth interspace in the midsagittal plane of the chest. The higher and lower locations are offset superiorly and inferiorly to the middle point by 50mm, as shown in Figure 1, which is a schematic representation of THUMS and the Hybrid III with the illustrated outline and distribution of the two pendulums used at the different impacted heights. The results were evaluated using the C_{max} (Kroell et al. 1971, 1974) and VC_{max} criteria (Lau et al. 1986) for hard and soft tissue (i.e. bones and organs) injury responses, respectively. The data was derived from motions of selected nodes from the finite element mesh. Since the data extracted from the Hybrid III was sampled internally, a factor of 1.3 was used to compensate for external to internal measurements when calculating VC_{max} as proposed by Lau et al. (1986). The data was filtered according to the SAE J-211 standard and recalculated to represent physical measurement sensors that may be used in crash testing.

This study was confined to finite element setups using impactors only. Cabin interior components such as seat, deformable steering wheel, seat belt and knee bolster were omitted from this study to isolate the response of the chest. Some initial assumptions were made: the responses of the THUMS model were assumed to reflect the response of a 50%-ile human. The C_{max} criterion was assumed to be valid for the chest in a hub-type impact. The VC_{max} criterion was assumed to be valid for the chest with no distinction regarding distribution. The present method should be seen as a principal method of utilizing Human Body Models (HBM) to evaluate the performance of dummy models. The accuracy of the method will depend on the validity of the HBM and the injury criteria.

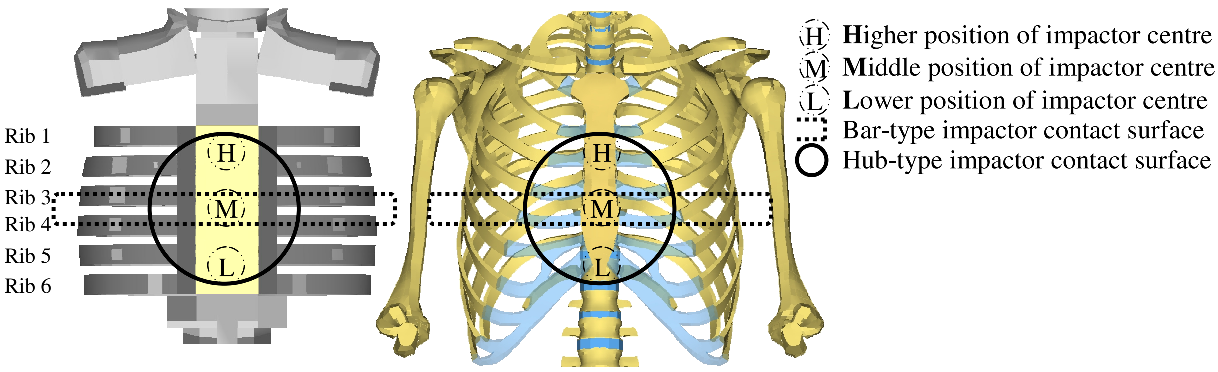

Figure 1 - Schematic view of impactor setups. Impact locations and load distribution visualized, grouped with the models of the Hybrid III (left) and THUMS (right) chest. Ribs of Hybrid III numbered 1-6, top to bottom.

RESULTS

In the first part of the study, peak deflection data (D_{max}) of the Hybrid III thorax chest potentiometer was compared to deflection at the actual point of impact (Figure 1). The D_{max} turned out to change depending on measurement method and on impact location and impactor type. The results show that the bar-type impactor generally produces the largest local deflection, while the hub-type impactor showed the largest deflection according to the potentiometer readout. The deflection pattern indicates a linear deflection relation between the ribs of the Hybrid III (Figure 2). The two vertical bars in each of these six diagrams show the location of impact as well as the local deflection at this point and the cross and circle markers show the deflection of each of the other ribs (left to right marker represent rib 1 through 6 respectively) when maximum deflection at impact location is reached. The dash-dot-dash lines show the linear representation from rib 1 to rib 6. The horizontal solid and dashed lines show the reading from the potentiometer of the Hybrid III. The results indicate that for a distributed load, such as the hub impactor, the potentiometer shows a deflection more similar to the one deduced at the centre point of impact. For the localized loading, however, the deflection measurements are significantly different. Note that the lower part of the sternum came into contact with the spine for both-types of impactor at the sixth rib and location. For the bar impactor this was also the case as the impactor struck the fifth rib.

The results from the second part of the study show noticeable differences in chest response of the Hybrid III compared to the THUMS. These results can be viewed in (Figure 3). This figure is divided into six parts, each of which show the chest response acquired from an impact using the hub- or bar-type impactor for the THUMS and the Hybrid III at the point of impact. For comparative reasons the response recorded by the Hybrid III potentiometer is also included. The top three diagrams show C_{max} and the bottom three diagrams show VC_{max}. The point of impact is shown at the bottom of the figure, e.g. the two leftmost groupings of bars representing the higher point of impact and so on. When comparing the results from the hub to those of the bar, a systematic difference in response can be found. The bar yields a higher response regardless of impact location and velocity for THUMS. The Hybrid III shows the same trend in the lower impact location. The largest differences in response between the THUMS and the Hybrid III can be seen for impacts to the higher and lower parts of the chest. Similarly to the results of the first part of this study the bar impactor at the lower location caused the sternum to come into contact with the spine in the 6.7 m/s impact.

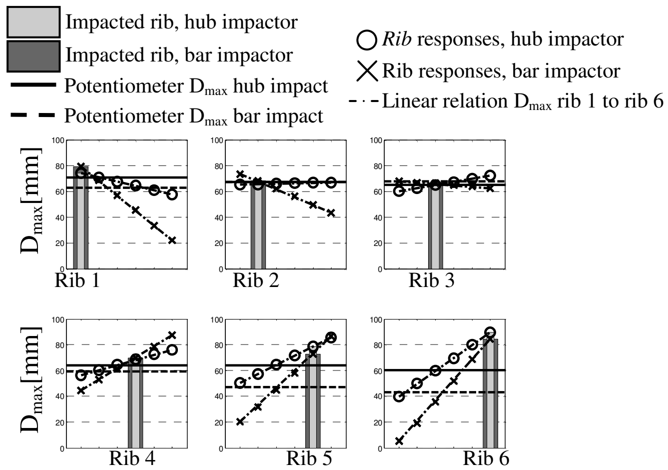

Figure 2 - Results from the first part of study; impacts to individual ribs and the deflection responses at 6.7 m/s.

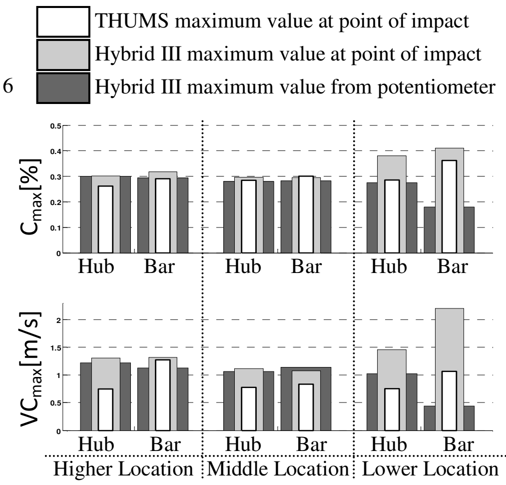

Figure 3 - Results from the second part of study at 6.7 m/s; Comparison of criteria responses of Hybrid III and THUMS.

By linking the response from the Hybrid III by a conversion factor, an anticipated response in the human model may be calculated. This factor is calculated for each criterion, load distribution and impact location and will therefore result in a table with factors to correct the results from the Hybrid III (Eq.1 and Table 1).

The hub at the middle impact location was selected as the reference response of the two criteria. All C_{max} and VC_{max} responses were normalized against this load case, at the corresponding speed. These cases had the greatest similarities to the original setup (Kroell et al., 1971, 1974 and Lau et al., 1986), from which these criteria have been developed. This gives a conversion factor of 1 for all responses in the reference cases. All responses in the bar cases as well as the higher and lower impact location hub cases will be given a conversion factor in relation to the middle location hub response (Eq.1 and Table 1).

$$Normalized\ Criteria\ Conversion\ Factor\ = \frac{THUMS\ Response}{HIII\ \ Response} * \frac{HIII\ Reference\ Response}{THUMS\ Reference\ Response} \qquad \text{(Eq. 1)}$$

Table 1 - Normalized criterion conversion factors for converting Hybrid III responses into anticipated responses of the THUMS. The worst case factors are summarized in the bottom two rows.

	Cmax			VCmax		
	Higher	Middle	Lower	Higher	Middle	Lower
Hub 6.7 m/s	0.90	1.00	0.79	0.82	1.00	0.74
Bar 6.7 m/s	0.95	1.06	0.92	1.39	1.11	0.70
Hub 4.3 m/s	0.92	1.00	0.81	0.78	1.00	0.67
Bar 4.3 m/s	0.88	1.04	0.90	0.96	1.00	0.93
Hub Factor	0.92	1.00	0.81	0.82	1.00	0.74
Bar Factor	0.95	1.06	0.92	1.39	1.11	0.93

DISCUSSION

Based on the results from this study a new method to interpret the chest deflection data is proposed. This method requires the Hybrid III chest to be additionally instrumented to be able to detect true deflection data from impacts that are not centered in the middle of the chest. The current shortcoming of the standard Hybrid III chest deflection sensor, with respect to load distribution and impact location, increases the risk of misinterpretation of the biomechanical results acquired during a truck frontal crash test. The results from the first part of the study indicate that the Hybrid III sternum deflects as a rigid plane. This would allow for a correct sagittal deflection of the sternum to be calculated by the use of two deflection sensors, mounted at top and bottom of chest, supplemented by a known location of impact.

Impacts to the middle location using the hub impactor produced similar C_{max} results for both the Hybrid III and the THUMS models. This may be due to the fact that they were both adapted to respond according to the response corridors developed by Kroell (1974) and subsequently scaled to 50%-ile by Neathery (1974). However, as the impactor struck the chest at the higher and lower location, the results diverged. New correction factors were proposed for calculating criteria responses, based on the relation between the responses of the HBM and the Hybrid III model at the different impact levels and with the different pendulum types. If better validated HBMs become available in the future, the current study could be repeated and these correction factors upgraded.

This paper offers suggestions on how to evaluate the extended use of existing dummies by means of finite element simulations. Anticipated responses of the human in relation to that of the dummy have also been proposed by creating a new unique set of chest deflection correction factors for use with the Hybrid III in heavy vehicle frontal impact tests. The paper also deals with a highly relevant commercial vehicle load case that until now has been almost unexplored in the field of biomechanics, dummy development and injury predictions.

CONCLUSIONS

- Care must be taken when interpreting the responses from the standard chest sensor of the Hybrid III in an event of truck steering wheel rim impact.
- The Hybrid III may be used for injury risk assessment for steering wheel impacts to the chest area.
- Additional instrumentation is needed for the Hybrid III.
- A correction factor can be used to predict the expected response of a human for non-central impacts.

ACKNOWLEDGEMENTS

This study has been conducted at Chalmers University of Technology and has been funded by the Swedish Vehicle Research Program (PFF) through VINNOVA.

REFERENCES

Cavanaugh, J., Nyquist, G., Goldberg, S. and King, A., Lower abdominal impact tolerance and response. 30th Stapp Car Crash Conference. (1986). pp 41–63.

Iwamoto, M., Kisanuki, Y., Watanabe, I., Furusu, K., Miki, K., and Hasegawa, J., 2002, Development of a Finite Element Model of the Total Human Model for Safety (THUMS) and Application to Injury Reconstruction, in Proceedings of the 2002 International Research Council on the Biomechanics of Impact (IRCOBI), Munich, pp 31–42.

Kroell, C., Schneider, D. and Nahum, A., Impact tolerance and response of the human thorax. 15th Stapp Car Crash Conference. (1971). pp 84–134.

Kroell, C., Schneider, D. and Nahum, A., Impact tolerance and response of the human thorax II. 18th Stapp Car Crash Conference. (1974). pp 383–457.

Lau, V. and Viano, C., The viscous criterion - bases and applications of an injury severity index for soft tissues. 30th Stapp Car Crash Conference. (1986). pp 123–142.

Neathery, R. F., Analysis of chest impact response data and scaled performance recommendations. 18th Stapp Car Crash Conference. (1974). pp 459–493.

Nyman, S., Bylund, P-O. Lastbils- och bussförare som skadats i yrkestrafiken, 125, Akut- och katastrofmedicinskt centrum, Norrland University Hospital, Umeå, Sweden. (2005)