Investigation of Injury Metric Sensitivity to Thorax Impact Loading Using a Human Body Model

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I. INTRODUCTION

Severe loading to the thorax is a significant source of occupant injury and fatality, particularly in side impact conditions. In 2012, 34% of all fatalities in multi-vehicle car crashes were attributed to side impacts [1] with the most common source of thoracic injuries in real world crashes being contact with the door [2]. Recent integration of torso airbags in vehicles has reduced these injuries by 8% and a combination of torso airbags with inflatable curtains was found to further reduce fatalities [3]. Understanding the response of the occupant to different loading conditions is important for improving restraint systems and safety. Standard vehicle compliance tests for side impact include a moving deformable barrier (MDB) impact (NCAP or FMVSS 214) with an anthropometric test device (ATD) in a predefined position. The integration of human body and vehicle models provides a unique opportunity to evaluate complex loading scenarios in a detailed manner. Human Body Models (HBM) can account for local factors related to occupant anatomy that may not be covered by global responses used for the current injury metrics. The goal of this study was to compare the predicted local versus global response of the thorax to evaluate sensitivity to loading conditions.

II. METHODS

Three different impact scenarios were investigated using a detailed finite element HBM including: lateral pendulum (Fig. 1a), NHTSA and WSU type rigid wall side sled impacts (Fig. 1b), and full vehicle NCAP side impact at 61 km/h (Fig. 1c, d). The vehicle FE model (2001 Ford Taurus, NCAC) included a seat and belt system. The models were solved using commercial implicit finite element software (LS-Dyna v971 R4.1, single precision, LSTC) and the HBM model was assessed using thorax deflection and the Viscous Criterion. A cross-correlation method (CORA, Partnership for Dummy Technology and Biomechanics) and maximum thorax deflection and VC values were used to evaluate the HBM response for the different load cases. The pendulum and side sled simulation results were compared to available PMHS data. The vehicle, barrier and occupant models have been previously validated against available data [4-7].

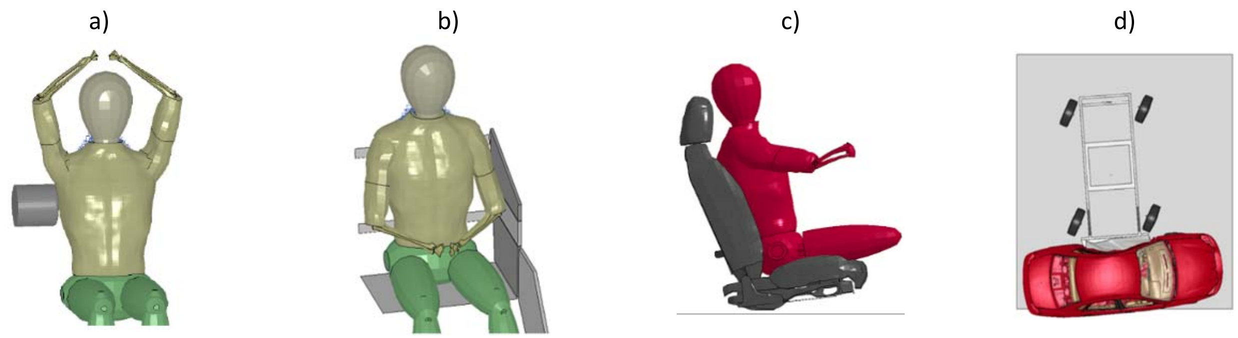

Figure 1: a) Lateral pendulum impact setup; b) NHTSA sled setup; c) HBM integrated with the vehicle in a nominal driving position; d) moving deformable barrier setup.

III. INITIAL FINDINGS

Pendulum impact results were in good agreement with the PMHS data and demonstrated increasing injury metrics with increased impact velocity. It was also noted that the deformation of the thorax was largest under the impact site, as expected. Side impact sled tests were in agreement with PMHS data but significant differences between upper, middle and lower chest band locations were noted (Table 1). Model assessment

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based on maximum thorax deflection compared to values calculated at three chest band levels in the thorax model demonstrated individual chest band location sensitivity to changing loading conditions. For the sled impacts, the maximum thorax deflection was observed at the lower band level while maximum deflection occurred at the upper band level (Table 1) for full vehicle impact and lateral pendulum impact.

Table 1: Maximum thoracic deflection for different loading types (bold indicates maximum value)

	Thoracic deflection [mm]		
Loading type	Upper band	Middle band	Lower band
Lateral pendulum 4.3 m/s	**32mm**	31mm	25mm
WSU sled 6.7 m/s	100mm	129mm	**138mm**
NHTSA sled 6.7 m/s	93mm	132mm	**153mm**
NCAP, 61 km/h	**66mm**	38mm	49mm

For different arm position (drive, vertical and horizontal) in full vehicle side impact, maximum chest deflection and VC values were increased for the vertical arm position (Figure 2). The sensitivity of individual chest bands to load cases was evaluated using a cross-correlation method (CORA, Table 2) where a value of 1.0 indicated excellent correlation between the curves. In this study, low values indicated a significant effect or change. For the standard driving arm position, the maximum deflection occurred at the upper chest band (66mm). In contrast, when the arm was vertical the maximum deflection value was observed for the lower chest band (133mm, Figure 2).

Table 2: Arm position sensitivity (range 0.0-1.0)

correlation rating	Deflection	VC
Upper	0.820	0.763
Middle	0.697	0.699
Lower	0.758	0.753

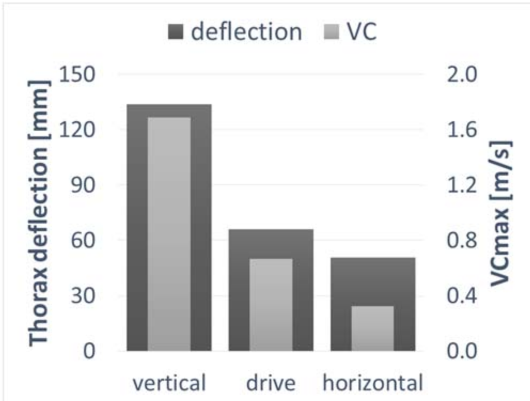

Figure 2: Maximum deflection and maximum VC response for different occupant arm positions

IV. DISCUSSION

This study investigated predicted HBM impact response evaluated in terms of global injury metrics (maximum VC and thoracic deflection) and local thorax response for three load cases. Pendulum impact allowed for evaluation of the localized impact, while sled impact provided a distributed load, and the full vehicle and moving deformable barrier impact evaluated interaction between occupant and the car door. Full vehicle simulations with different arm positions of the HBM were presented in order to highlight the sensitivity of individual chest band locations to changing loading conditions. Cross-correlation analysis provided an opportunity to assess HBM response in an objective manner and identify effects that were not noticeable using the typical global thorax response (maximum deflection, maximum VC). The local evaluation identified potential areas for improvement in side impact safety through modifying restraints or door contact area. Future studies will include an evaluation of the internal organ response in the HBM and a direct comparison to ATD model response in the same loading scenarios.

V. REFERENCES

[1] IIHS Fatality Facts, 2012 [2] Morris A et al, IRCOBI, 1997 [3] Kahane CJ, NHTSA Report No. DOT HS 811 882, 2014 [4] Forbes P, MASc thesis, 2005 [5] Yuen K, MASc thesis, 2009 [6] Watson B, Jcrashworthiness, 2011 [7] Campbell B, JCrashworthiness, 2014.