Methodology to Calculate Chestband Compressions in Human Body Finite Element Models

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I. INTRODUCTION

Human body finite element (FE) models are used to understand occupant kinematics-kinetics and to develop countermeasures [1]. Chest compressions using chestband are needed to validate the human body models (HBMs), however the calculation of chest compression is a challenge for researchers [2,3]. Hayes *et al.* proposed a method to calculate chestband compression, using the local coordinate system, defined with three chestband nodes [2]. Due to the relative transformation, use of the local coordinate system may lead to less accurate reading of coordinates, especially when relative rotation of the chest occurs (e.g. far-side impacts). The objective of this study is to develop a robust methodology that can be used to measure chest compressions for FE human surrogate models in any impact scenario.

II. METHODS

A full-scale simulation was performed using the Global Human Body Models Consortium (GHBMC) HBM seated in a vehicle model [4]. The vehicle was impacted on a rigid pole at B-pillar under far-side condition at 10 m/s. The initial and final positions of the HBM are shown in Fig. 1. The occupant position can be observed to have changed in all 6 degrees of freedom. The chestband consisted of 32 nodal points at T11 vertebra level. LS-PrePost was used to obtain the global coordinates of 32 chestband nodes and two additional nodes on the T11 vertebra, for the entire crash duration at 10 kHz. An algorithm was developed to calculate the peak chest compression and was implemented with a custom MATLAB code.

The T11 vertebra was considered as reference for the transformation of the chestband. Thus, the translational and rotational matrices were calculated using coordinates of the two nodes on the vertebra. The translation was the difference in the x, y, z coordinates, for each time step. Whereas, the rotation was about the x, y, z axes at respective angles, for each time step. The transformed chestband coordinates (C_T) were calculated using homogeneous transformation matrix (T_{xyz}) and nodal coordinates of each node (C) at every time step (Fig. 2). The peak chest compression was calculated using the transformed nodal coordinates with the two methods: (1) node-to-node transformation, and (2) nodal transformation with respect to vertebral reference. The node-to-node transformation was calculated as the change of position of a chestband node with respect to initial position, at every time step. The nodal transformation with respect to vertebra was calculated as change of position of a chestband node with respect to the vertebra, at every time step.

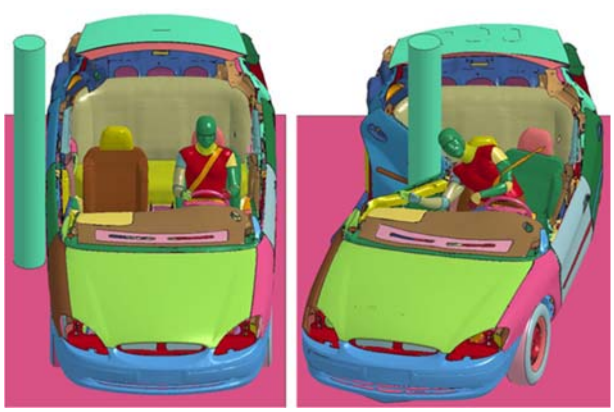
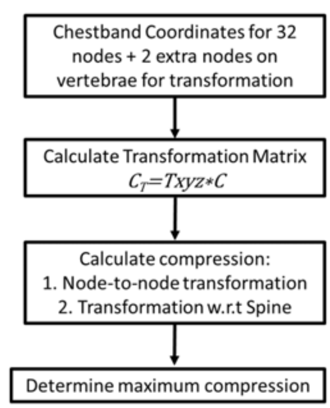


Fig. 1. Simulation setup (left), occupant position at the end of the crash event (right).



$$Txyz=\begin{bmatrix} R_{11} & R_{12} & R_{13} & T_x \\ R_{21} & R_{22} & R_{23} & Ty \\ R_{31} & R_{32} & R_{33} & Tz \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Fig. 2. Algorithm to calculate chestband peak compression.

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III. INITIAL FINDINGS

The chestband contour profiles at the time of peak chest compression for the two methods are shown in Fig. 3(a) and (b). The black curve represents the pre-crash, undeformed chestband contour, and the red curve represents the chestband contour at the time of peak chest compression. The green points indicate the node with peak chest compression and the connecting green bars indicate the method of calculation of peak chest compression. The peak chest compression using node-to-node transformation method was 74 mm at 90 ms (milliseconds), whereas the peak chest compression using nodal transformation with respect to the vertebra method was 45 mm at 110 ms.

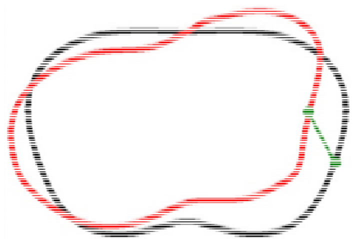

Fig. 3(a). Chest band profiles and peak chest compression using node-to-node transformation.

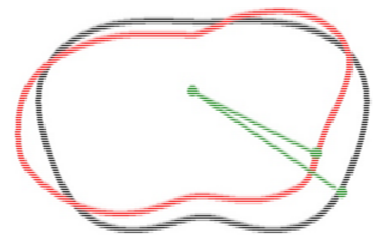

Fig. 3(b). Chest band profiles and peak chest compression using vertebral reference.

IV. DISCUSSION

In this study, the chestband data from a full-scale vehicle impact simulation was used to calculate the peak chest compression using two methods. A custom code was developed to transform the chestband nodes with respect to the thoracic vertebra. The transformation was performed by translating and rotating chestband coordinates about the x, y, z axes, using vertebra as the reference. The chest compression was calculated using two methods. The peak chest compression calculated with node-to-node transformation method was higher than the compression using the nodal transformation with respect to vertebra method. The first method considers the shearing of the chest. Thus, the higher chest compression is expected. Whereas, the second method minimises the shearing effect, and focuses on the pure compression of the chest at a node. At 90 ms the seatbelt slipped off the shoulder, reducing the shearing effect on the chest, thus showing maximum compression for the first method. Whereas, at 110 ms, the belt slipped completely from the forearm, thus making the restraint system ineffective and resulting in the highest chest compression, which was predicted by the second method.

Experimentally, to measure the external peripheral deflection contours, chestbands in PMHS tests are positioned and attached to measure chest compressions. The vertebra reference method appears to achieve this objective, thus making the HBM validation processes more robust, an essential feature for any FE model [5,6]. The novelty of this study is the development of a robust methodology used to perform transformation of the chestband data. The flexibility of choosing transformation points at any location (vertebra in this case) resulted in accurate translation and rotation of the chestband contours. If a predefined local-coordinate system is used, as suggested in the literature, then the flexibility of changing the coordinate system is lost, unless some other reference nodes are added to the local coordinate system. Additionally, this study demonstrates a way to transform the coordinates in all 6 degrees of freedom. Due to the flexibility of choosing the nodes for transformation, the proposed method for calculation of peak chest compression is appropriate for different crash scenarios, in addition to the parallelism with the experimental data collection processes.

V. REFERENCES

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