Influence of Rib Fracture on Chest Deflection by Using FE Human Body Model in Frontal Impact

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I. INTRODUCTION

The probabilistic prediction method based on post processing as well as finite element Human Body Models (HBMs) were used together to study chest injury. In this kind of study, the HBM is set as a "non-fracture" model due to the probabilistic prediction method. This study was aimed at analysing the chest deflection difference between models with rib fracture enabled and disabled, and the difference between two levels of rib fracture, in a simplified frontal impact condition with the regular seatbelt. A sensitivity analysis was conducted with the rib fracture element elimination functionality enabled at four magnitude levels of fractured ribs – none (fracture turned off), fracture enabled in five ribs, fracture enabled in ten ribs, and fracture enabled in all of the ribs. Chest deflections at four points were obtained from these simulations and compared.

II. METHODS

In the implementation of probabilistic rib fracture prediction based on local rib strains in human body finite element models [1], it is assumed that fractures of a small number of ribs will not affect the total stiffness of the ribcage stiffness. There is likely an upper limit to this assumption, however, where a large-enough number of fractured ribs will likely destabilise the ribcage and increase the amount of chest deflection for a given load. Some work has been done to study the influence on the whole body kinematics during side impact because of the assumption [2]. The aim of this study was to investigate the effect of rib fractures on chest deflection in a frontal impact simulation using the Global Human Body Models Consortium (GHBMC) human body model. The GHBMC model was originally developed by several universities and all the corresponding changes are based on the reference experimental work [3]. To study the sensitivity of chest deflection to rib fracture, simulations were performed with and without element elimination. Simulations were performed in the Gold Standard One (regular seatbelt) frontal sled test condition (Fig.1).

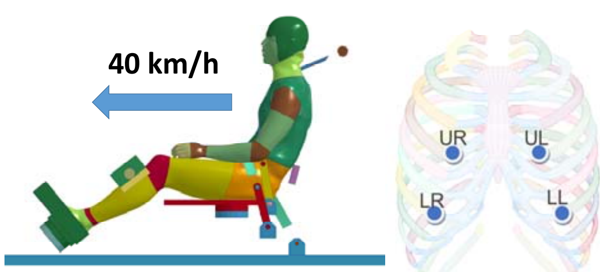

Fig. 1. Gold Standard experimental frontal impact.

TABLE I

SIMULATION MATRIX

Simulation ID	No. of fracture ribs Enabled	Rib 1 Fracture
S 1	All	Enabled
S 2	None	Disabled
S 3	First 5	Disabled
S 4	First 10	Disabled
S 5	First 5	Enabled if first 5

The total number of simulations in the simulation matrix was five (Table I). Varied parameters included the number of fractures that were allowed to occur (none, 5, 10, and unconstrained/all). To study the effect of the first rib, simulations were also performed where the first rib specifically was not allowed to fail. The occurrence of fracture was controlled by either enabling or disabling element elimination in the ribs. Disabling element elimination meant that the ribs would keep the element undeleted though some of the elements might reach or exceed the failure strain of the cortical bone. All the thorax deflection results were exported and compared. All the deflection results were listed to illustrate the difference of the chest outcome caused by the different rib fracture definitions. Simulations were performed with the LS-DYNA software.

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III. INITIAL FINDINGS

The results demonstrate that the deflection magnitude of the four measurement points obtained from the simulation increased when the element elimination method (fracture model) was utilised, and the results varied by location (Fig. 2a and Fig. 2b) during frontal impact. The observed differences were small in the upper right (UR) and lower right (LR) measurement locations, and larger in the upper left (UL) and lower left (LL) locations. All the deflections occurred in the same directions as the experiment results. The lower right measurement point moved out from the body during the impact. The upper left, upper right, and lower left points were compressed (Fig. 2a and Fig. 2b).

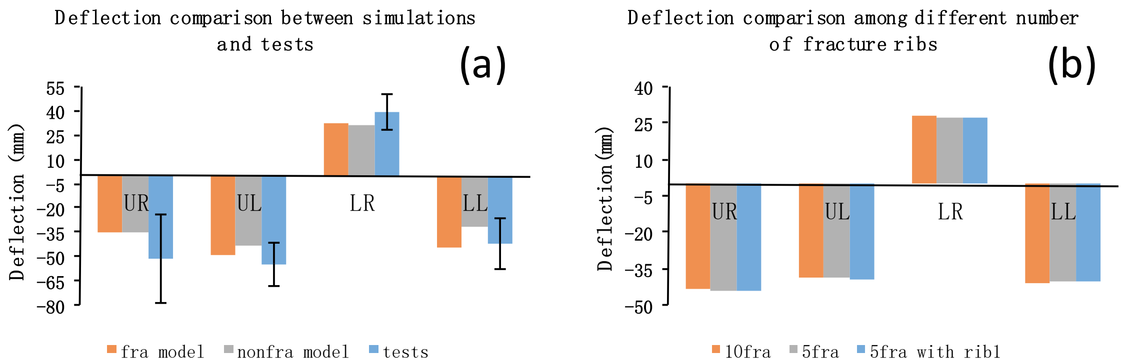

Fig. 2. Deflection results from the simulation matrix.

The thorax peak deflections estimated with or without the activation of element elimination were all in the range of the experimental peak chest deflection deviation. The differences were identified in all four measurement points; though more obvious differences were found in the left side which was more than 5 mm (Fig. 2a).

Models allowing the first five fractured ribs and the first 10 fractured ribs were compared. There was no difference found between these different levels of fractured rib simulations (Fig. 2b). A simulation with rib 1 fractures element elimination enabled was analysed, and not much difference was recognised (Fig. 2b). The largest difference observed in the LL point, which correlate with the other simulation comparison.

IV. DISCUSSION

The results of this study indicate that relatively large numbers of fractured ribs (≥5) have the potential to affect the amount of chest deflection observed in certain regions for a given applied load in frontal sled tests. These tests, however, represent a relatively severe condition, where seven out of the eight cadavers tested exhibited >5 fractured ribs. Future work should include a complementary sensitivity analysis at a lower severity to identify the threshold for the number of fractures that begin to affect ribcage stiffness. In addition, this study only investigated the effect of fractures on the overall deflection of the ribcage. Future work should also investigate the effect of fractures on the prediction of strain elsewhere in the ribcage, and how that might affect tissue-level injury prediction.

V. REFERENCES

[1] Forman JL et al, AAAM, 2012.
[2] Motozawa Y et al, IRCOBI, 2015.
[3] Shaw CG et al, Stapp Car Crash J, 2009.