Change of lateral chest compression values due to bone failure in side impacts

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I. INTRODUCTION

Side-impact crashes lead to 28% of road deaths in developed countries [1], and 58% of those fatalities occur due to thoracic injuries [2]. Experimental studies, utilising post mortem human subjects (PMHS) and anthropometric test devices (ATDs) [3-9] to investigate occupant interaction with side restraints, have yielded contrasting thoracic response depending on occupant surrogate type. To verify the experimental results, numerical models have been used to simulate occupant response in side impacts. Biofidelic Human Body Models (HBMs), verified and validated for multiple impact directions [10], have demonstrated and confirmed the experimental findings that the effect of changes in arm position [11], thoracic side airbag and seatbelt settings [12], and chest compression measurement method [13] vary for ATDs and HBMs.

One difference between PMHS and ATDs that has not been studied is frangibility. While PMHS predict both hard and soft tissue response directly, ATDs are not frangible. Since the vehicle compliance testing utilises ATDs [14] and side-impact safety criteria include chest compression [14], it is important to understand the effect of frangible versus non-frangible occupant surrogates for the predicted thoracic response. HBMs are ideally suited for analysing the effect of frangibility since hard and soft tissue failure can be toggled on and off. This study compares chest compression predicted by the HBM in standard lateral pendulum and sled impact scenarios with rib failure enabled and disabled in the model.

II. METHODS

A detailed HBM (GHBMC-O M50 v.4.3) was integrated with a free-flight lateral pendulum [15], and with two side-impact sleds based on the WSU [16] and NHTSA [17] geometry (Fig. 1). In the experimental pendulum impacts [15] with PMHS, the arms were moved from the load path, and in the sled impacts the arms were placed in the load path [16-17]. In this study, an arm down position where the upper arm was aligned with the torso (Fig. 1) was considered in both pendulum and rigid sled simulations.

Pendulum
ϕ152mm, 23.4 kg, 4.3 m/s

NHTSA
6.7 m/s

WSU
6.7 m/s

Fig. 1. Pendulum and rigid sled lateral impact conditions.

Integration of the HBM with pendulum and sled

For the sled impacts, the HBM was located above the seat and gravity was applied to the occupant body until a physiological position was achieved and pelvic vertical acceleration reached zero. The motion of the head, upper torso and legs was then constrained and gravity was applied to the upper extremities until the desired arm position was achieved. For the pendulum impacts the same model was used, and a rigid impactor was integrated with the HBM at the level of rib 6 and constrained to move in coronal plane only, matching the experimental set-up [15]. Chest-band chest compression was measured as a change in length between markers

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placed on the skin at three locations: upper, middle and lower [17-18], corresponding to locations of ribs 8-9-10. Rib compression was measured directly on ribs 4, 6, 8 and 10 [13] as a change in distance normalised by initial rib breadth. Both methods were used to assess chest compression with and without bone failure. Bone failure was enabled in the model by eroding rib elements once they exceeded a defined plastic strain threshold (1.8% for cortical bone, and 13% for trabecular bone) [10].

III. INITIAL FINDINGS

Both chest band and rib compression methods predicted lower chest compression when bone failure was disabled for all impact scenarios (Fig. 2). Chest compression change was more pronounced in sled impacts than in pendulum impacts due to higher energy loading, and more significant when measured directly on the ribs (11–26% decrease) compared to the chest-bands (4–14% decrease).

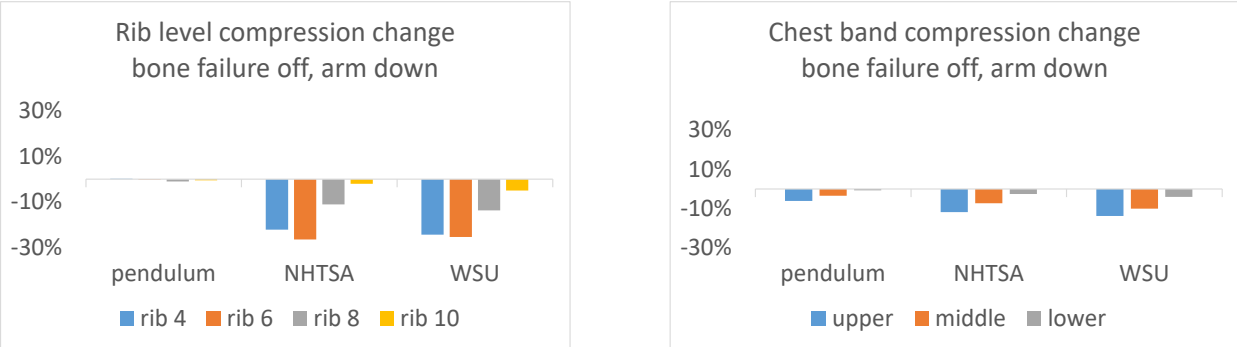

Fig. 2. Chest compression change due to disabled bone failure for two measurement methods.

IV. DISCUSSION

The HBM enabled prediction of rib deformation when bone failure was toggled on and off, simulating a frangible (PMHS) and a non-frangible (ATD) occupant surrogate. Predicted chest compression values decreased as much as -26% when bone failure was disabled in the model. The magnitude of the effect was dependent on the assessment method used, where the chest band thorax compression yielded higher sensitivity due to the deformation of soft tissues surrounding the ribcage. Therefore, the treatment of bone failure for predicted thorax response could affect interpretation of chest compression data predicted by frangible versus non-frangible occupant surrogates. Further studies will assess the effect of chest bands as mechanical constraints for the predicted chest compression. Full vehicle simulations will be conducted to predict rib fracture locations, and investigate the effect of varying arm positions and the effect of bone failure for occupant interaction with restraints.

V. ACKNOWLEDGEMENTS

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VI. REFERENCES

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