Numerical Investigation of Behind Armour Blunt Trauma to a Range of Thorax Locations

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I. INTRODUCTION

Personal armour systems are worn by law enforcement and armed forces to protect users from hazards such as sharp objects and projectiles. While these systems can defeat incoming threats, they deflect inwards towards the user as part of the energy dissipation process, ultimately applying a blunt impact to the underlying tissue. This can manifest in the form of bruising, bone fractures and organ injuries. Current armour designs are governed by National Institute of Justice (NIJ) Standard-0101.06, which calls for a maximum backface deformation (BFD) of 44 mm on ballistic clay [1]. This assessment operates on a pass/fail basis and does not indicate likelihood nor severity of injury. Furthermore, the 44 mm limit is proposed for the entire thorax, and does not consider location specific needs. Human body models (HBMs) have emerged as a promising alternative to experimental testing, providing a consistent tool for injury mechanism assessment. These HBMs have previously been used to investigate injury risk under high-rate loading conditions that would prove difficult to conduct experimentally. Previous numerical work using a proprietary model found the thorax to be susceptible to injuries below the 44 mm standard at various locations along the anterior aspect [2]. The present work leverages the use of an openly available HBM to assess how impact location, including aspect (anterior/posterior), anatomical level and structure (rib/vertebra) can affect injury susceptibility in the thorax under behind armour blunt trauma (BABT) loading conditions.

II. METHODS

The Global Human Body Models Consortium (GHBMC) 50th percentile male HBM V5 segmented pedestrian torso was selected for the present study. Previous work from our group [under revision] simulated ultra-high molecular weight polyethylene (UHMWPE) armour under ballistic impact. The evolving profile of the armour was extracted to be applied anywhere on the HBM, using a 40 x 40 shell structure, with a given mass of 34 g (Fig. 1a). To investigate injury risk at various locations, multiple ribs were impacted in the anterior and posterior aspects, along with several vertebrae levels (Fig. 1b-c). Anterior impacts were aligned to the costochondral junction and posterior impacts were aligned to the midpoint of the arch height of each selected rib. Element erosion (cortical and trabecular) was used as a proxy for injury severity in both the ribs and vertebra, defined as 2.0 and 6.7% for cortical and trabecular components, respectively. The damaged elements were normalized with respect to the total elements for the entire level (cortical and trabecular) for the rib and vertebra as well as all elements of the costal cartilage, which was not separated by level. The commercial finite element solver LS-DYNA R14.1 was used to conduct all simulations.

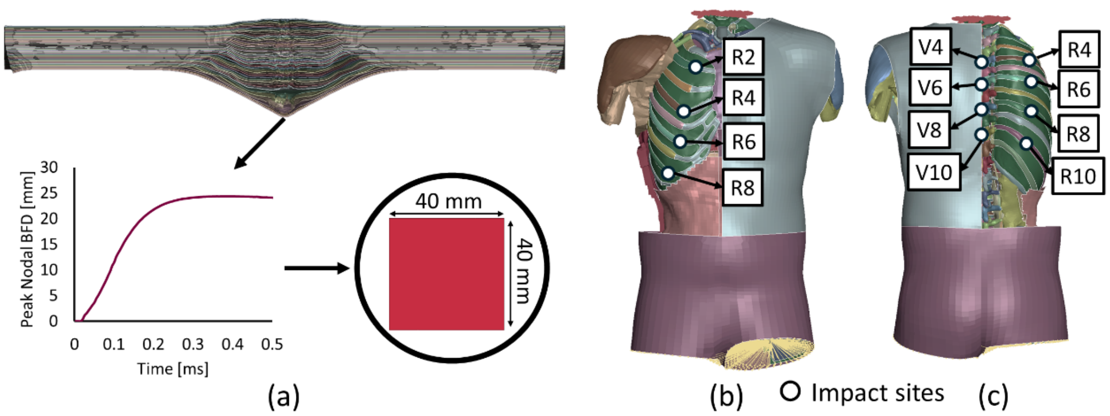

Figure 1: (a) Moderate BFD profile from UHMWPE modelling that was applied to the HBM. Impact sites are annotated for (b) anterior and (c) posterior/vertebral aspects where R = rib and V = vertebra.

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III. INITIAL FINDINGS

All simulations terminated successfully. Fractures were predicted across all simulations, with damaged elements ranging from 0.1-8.3%. The number of elements damaged indicated that anterior impacts were more "severe" than posterior ones; the average elements damaged for anterior and posterior impacts were 4.9% and 1.5%, respectively (Fig. 2). The vertebrae had an average element damage of 4.7%, comparable to that of ribs under posterior impacts. Furthermore, injury tended to increase the more inferiorly the impacts were applied, suggesting users may be more vulnerable at these lower anatomical levels.

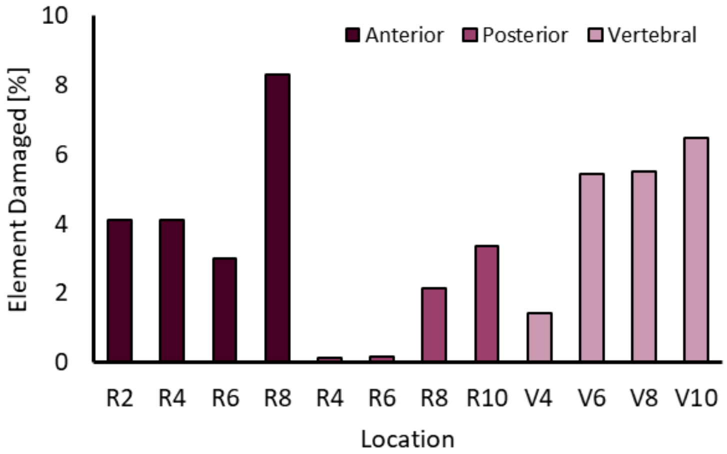

Figure 2: Elements damaged due to BABT impacts at various levels and aspects, normalized to all elements in the level (rib and vertebra and costal cartilage).

IV. DISCUSSION

The present work aimed to identify regions where injuries are more likely to occur under a given BFD. Element damage values were normalized to comparatively assess all impacts and identify regions that may be more prone to injury. Despite the usage of a much lower BFD than 44 mm (current NIJ standard), bone fractures occurred in all simulations. Furthermore, injuries were worse overall when impacts were aligned with lower levels, indicating various regions may possess different BFD limits. Vertebrae were previously reported to be highly susceptible to injuries from BABT [3], [4], highlighting the importance of considering impact location. Soft tissue and organ injuries were not considered in this work, and more stringent BFD limits may be required to protect underlying anatomical components such as the liver or spleen at lower levels. Next steps should focus on predicting organ injuries at various locations and BFD, given their importance for positive health outcomes.

Numerical modelling of BABT is challenging and has necessary associated simplifications. The GHBMC was originally developed for automotive applications, with the thorax undergoing limited validation from hub experiments [5], and the material properties do not include characterization above 250 s^{-1}, potentially affecting injury prediction capabilities. The loading was also relatively concentrated, and the mesh density of the GHBMC was not altered in this work and may have influenced results. Furthermore, the presence of backing materials (biological, gelatin, etc.) was not included when modelling the armour, and thus the BFD and resulting stress/strain in the HBM may be overestimated. Regardless, parametric studies, such as the one presented herein, have the potential to bridge the gap between BABT and its associated injury mechanisms, and HBMs offer a consistent platform to conduct such investigations. This work demonstrated regions of elevated injury risk due to BABT using a HBM subjected to an evolving profile, providing valuable information for enhanced armour design.

V. REFERENCES

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