A Modelling Approach for Cross-Species Comparison of High-Rate Non-Penetrating Blunt Impacts

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I. INTRODUCTION

High-rate non-penetrating blunt impacts (NPBI) affect those who wear personal protective equipment (PPE) designed to prevent penetrating injury [1]. NPBIs can cause injury or even death due to the deformation of the PPE as the energy of the threat is transferred to the tissue beneath the site of impact [2]. *In-vivo* animal experimental models and finite element (FE) models have been utilised in the past to investigate the mechanism of injury in the high-rate NPBI environment [3-8]. One such study has used a validated FE ovine thorax model (FE-OTM) to simulate experimental high-rate NPBI ovine thorax impacts and reported peak force, energy, and impulse [7-8]. Computational models provide an ideal platform to translate findings from animal studies to humans. This study aims to compare the validated FE-OTM to a human body model (HBM) in a series of matched impacts simulating back face deformation (BFD). The ultimate goal of this research is to utilise these existing models to improve scaling techniques from ovine to human impacts, and eventually to translate injury observed in animal models to equivalent human outcomes. Such a model will be instrumental to developing improved PPE. In the current study ovine experimental NPBI boundary conditions that has been used for validation of the FE-OTM are applied to the human model and compared [7].

II. METHODS

Four high-rate NPBI impacts were selected from the FE-OTM validation simulation matrix to be simulated on the 50th percentile male Global Human Body Models Consortium (GHBMC) simplified pedestrian model (M50-PS v. 5.3.5) [9]. The GHBMC has been validated in the car-to-pedestrian space [9]. The selected impacts had a nominal impact velocity of 40 m/s, maximum depths ranging from 18.5 to 55.2 mm using two impactor heads (flat and hemispherical) simulating BFD. The impactor was positioned between the 6th and 7th rib in the intercostal space, similar to the experiments described previously as shown in Figure 1 [7]. The models were run in LS-Dyna using solver R12.2.1 (Ansys, Canonsburg, PA) to 10 ms using MPP on 32 cores and 72 GB of RAM using an in-house high-performance computational cluster. Simulation outputs included the contact force between the impactor and the model and the displacement of a node on the impactor head, both output at a frequency of 100kHz. The force outputs were filtered using a SAE J211 3 kHz filter and analysed in MATLAB R2024a (MathWorks, Natick, MA). For each impact, peak force, energy, and impulse were compared to the corresponding impact on the FE-OTM. Impulse was calculated from the integral of the force-time trace and energy from the integral of the force-displacement trace. Additionally, force-displacement traces were compared between the two models.

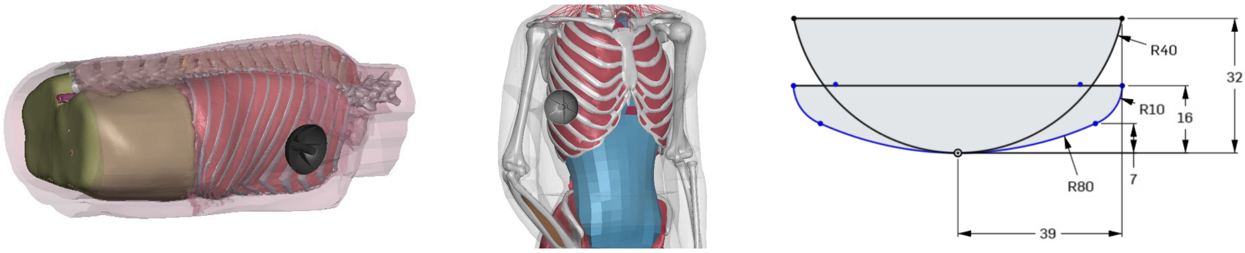

Fig. 1. (Left) FE-OTM (Middle) GHBMC M50-PSv5-3-5 (Right) Impactor profiles (flat and hemispherical) [7].

III. INITIAL FINDINGS

The initial findings include the comparison of the FE-OTM and the GHBMC M50-PS v. 5.3.5, with a primary focus on the resulting force, energy, and impulse. In Table 1, the peak force, energy, and impulse are listed for both impactor types, as well as the impactor head type for each of the four simulations run. In Figure 2, the force-displacement traces are compared between the FE-OTM and the GHBMC M50-PS. All four simulations, regardless of head type, resulted in higher forces in the GHBMC than in the FE-OTM. This may be driven by mass differences (M50-PS, 78.5 kg, vs. FE-OTM which ranges from 23.7 to 30.6 kg) or anatomical differences. However, the flat head impacts had greater initial forces than the hemispherical impacts (tests 3 and 4).

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TABLE 1
SUMMARY OF PEAK DEPTH, FORCE, ENERGY, AND IMPULSE FROM GHBMC AND FE-OTM [7]

Sim #	[7] #	Depth (mm)	Impactor Head Shape	Peak Force (kN) FE-OTM	Peak Force (kN) GHBMC	Peak Energy (J) FE-OTM	Peak Energy (J) GHBMC	Peak Impulse (Ns) FE-OTM	Peak Impulse (Ns) GHBMC
1	*3*	19.0	Hemisphere	3.27	9.38	44	87	1.28	2.32
2	*5*	55.8	Hemisphere	8.28	15.97	314	482	9.74	14.90
3	*10*	18.9	Flat	5.71	18.18	65	210	1.91	5.43
4	*12*	54.8	Flat	11.02	17.58	420	542	13.60	17.06

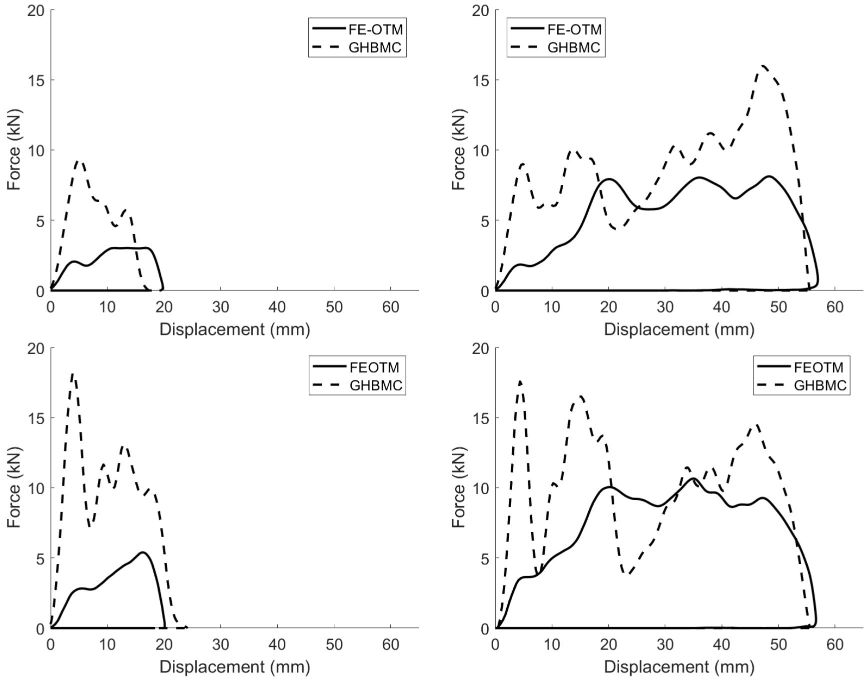

Fig. 2. Force-Displacement for Tests 1, 2, 3, and 4 at 40 m/s.

IV. DISCUSSION

The GHBMC M50-PS shows greater values than the FE-OTM at similar displacements. Peak force, energy, and impulse magnitudes are more similar for deeper impacts than shallow impacts. The GHBMC has a very fast peak on the shallow impacts not seen in FE-OTM. As a benchmark in similar loadings in other studies, other HBMs saw peak forces of roughly 25 kN, compared to this study's range of 9-18 kN in the thoracic region [10]. The larger magnitudes in force may be due to the differences in anatomy, particularly with respect to the chest shape and the adipose thickness. Additionally, the GHBMC experienced larger oscillations in the force response. This may in part, be due to the coarser mesh size of this HBM (15-20 mm) compared to the FE-OTM (6-12 mm) on the external surface closest to the impactor respectively. Computational models provide an ideal platform to better understand the differences in injury outcome across species and may be helpful to inform future scaling methods for both impact (e.g. energy, impulse) and injury (e.g. contusion volumes). Future studies will focus on a more comprehensive set of matched pair simulations and comparison of associated injury risk based on tissue level criteria such as lung parenchyma and rib cortex strain.

V. ACKNOWLEDGEMENTS

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