The Influence of Impactor Shape on Injury Severity for High-Rate Non-Penetrating Blunt Impacts using an Ovine Thorax Finite Element Model

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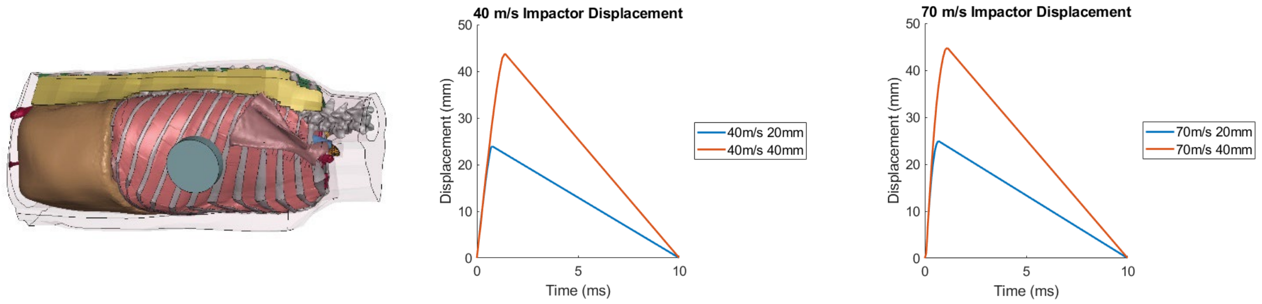
I. INTRODUCTION

High-rate non-penetrating blunt injuries (NPBIs) can cause injuries with serious complications, and even death [1]. To study some injuries in this environment, living animal subjects are required since post-mortem human subjects do not have the immune response required, as in the case of cause pulmonary contusion [1]. Ovine subjects are well suited for use as human surrogates in the study of NPBIs due to the anatomical and physiological similarities of their lungs and cortical bone [2-3]. Finite element models (FEMs) of the ovine subjects provide a useful complement for pre-test planning of experimental testing. This study uses the FE Ovine Thorax Model (OTM) to investigate whether the shape of the impactor in high-rate NPBIs influences the severity of the impactor. This analysis will be conducted by comparing impactors with varying heights of curvature in multiple impact severities and determining how the force and energy response is affected.

II. METHODS

This work was completed using a previously developed FE-OTM (Fig. 1A). The OTM model includes a detailed mesh of the torso ranging from vertebrae C5 to L4. The mass of the unmodelled portions (head, legs, pelvis) was accounted for using point masses. The model's geometry was based on computed tomography imaging and all constitutive material models used were derived from literature. The full model includes 3.2 million solid elements and 486 thousand shell elements, seven contacts, and 45 kinematic joints representing the spine and costo-vertebral junctions. The OTM was simulated in a series of 16 simulations, including four impact severities based on the impact velocity and depth (40 m/s, 20 mm, 40 m/s, 40 mm, 70 m/s, 20 mm, and 70 m/s, 40 mm) and four impactor shapes based on the height of the curved surface (henceforth, dome height of 10 mm, 20 mm, 30 mm, and 40 mm). The impactor had a radius of 40 mm, was located with an initial offset of 5 mm from the model's surface, and was positioned to make initial contact normal to the spine. The radius of the impactor was not changed, only the dome height. Lower dome heights presented a flatter impacting surface. The motion of the impactor was controlled using boundary prescribed displacement, which can be seen in Fig. 1 B and C. All impactor head shapes have a diameter of 60 mm, aluminum material properties, and a weight of 0.2 kg.



A B C

Fig. 1. A. Image of the model. Impactor displacements for 40 m/s (B) and 70 m/s (C) simulations.

The force imparted upon the model was extracted using the contact force between the impactor and the skin and was filtered to SAE CFC1000. Additionally, the displacement of the skin from the node closest to the initial point of contact was extracted and used to calculate the energy of the impact.

III. INITIAL FINDINGS

All 16 of the simulations successfully ran past peak force. The force and energy response with respect to time for the 40 m/s 20 mm impacts and a summary of the peak force and peak energy for all the simulations as a function of the impactor curvature can be seen in Fig. 2. In Fig. 2A, the peak force is seen to decrease non-linearly as the impactor dome height increases. Additionally, changing the impactor dome height has minimal effect on the time to peak or the contact duration. In Fig. 2B, the 40 m/s simulations are shown in black and the 70 m/s simulations are shown in red. The low depth (20 mm) simulations are shown with a solid line and the

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high depth (40 mm) are shown with a dashed line. The force response increases with impact speed and depth, and decreases with impactor radius. Similar to the force response, the peak energy decreases non-linearly as the impactor dome height increases and the time to peak is unaffected by the impactor radius. The displacement of the measured node was different from the prescribed displacement of the impactor as separation occurred between the skin and the impactor; however, impact depth had a greater effect than impact speed on the energy response. The peak force and energy of the impact quadratically decreases with increasing impactor dome height, R^2 value greater than 0.99.

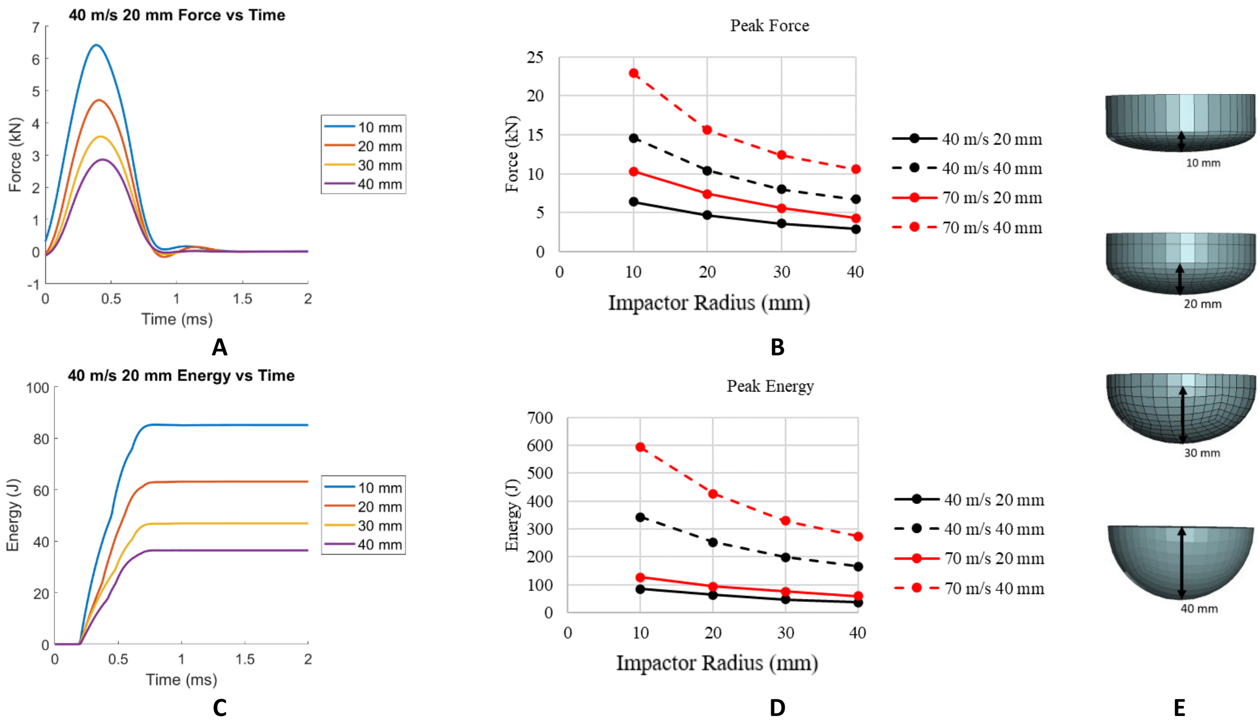

Fig. 2. A. Example time history trace of force for the 40 m/s 20 mm impacts for all impactor dome heights. B. Summary of the peak force of each simulation as a function of impactor. C. Example time history trace of energy for the 40 m/s 20 mm impacts for all impactors. D. Summary of the peak energy of each simulation as a function of impactor dome height. E. The different impactor dome heights.

IV. DISCUSSION

Currently, the OTM can be used as a pretest prediction tool to save time and subjects during the protocol development phase by determining how changes to the setup will affect outcome. This study shows an example application of the OTM by examining the effect of impactor shape on impact severity. The initial investigation revealed that impactor dome height affects impact severity and that the peak force and energy quadratically decrease with increasing impactor dome height. Further investigation is warranted to fully understand this relationship. A limitation of this work is that the OTM used has not yet been fully validated, so while the comparative changes between simulations hold true, the magnitude of the force and energy response may not. The findings from this study can be used to inform for the experimental design of high-rate NPBIs and allow researchers to understand how changing the shape of the impactor will affect the severity outcome of the experiment. We conclude that given equal input energy we would anticipate greater injury for a flatter impact face. Furthermore, this study suggests investigating methods that encourage a more hemispherical deformation surface may be an injury mitigation strategy. Future work will involve comparing model output to physiological measures from ovine experiments as a means to develop FE based injury metrics for NPBI.

V. REFERENCES

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