Finite Element Model of an Ovine Thorax for the High-Rate Non-Penetrating Blunt Impact Environment

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Introduction

Personal protective equipment (PPE) has been implemented to prevent penetrating injuries; however, this can still result in high-rate non-penetrating blunt injuries (NPBIs). Despite the presence of PPE, such impacts can still cause injuries with serious complications, and even death. Ovine subjects make for good models to study NPBIs since their lungs are anatomically and physiologically similar to humans. This study assesses the robustness of a recently developed finite element ovine thorax model (OTM) for use in this environment.

Methods

- Collected contrast enhanced CT scans of ovine subject (scan parameters: 100 kv, 400 mA, and 20s post contrast) and reconstruction using bone and soft tissue windows.
- Segmented structures: ribcage, sternum, C5 – L4, scapula, costal cartilage, heart, lungs, vasculature, liver, spleen, kidneys, rumen, and outer surface.
- Mesh developed for segmented and non-segmented structures using ANSA v22.0 (Beta CAE Systems, Farmington Hills, MI).
- Model includes 3.2 mil solid and 486 thousand shell elements.
- Robustness testing simulations were run in LS-Dyna (Ansys, Canonsburg, PA) using an intel-MPI 2018 Xeon64 and Linux CentOS 6.5 um with double precision.
- Test matrix (18 simulations for the high-rate NPBI environment): 2 impact velocities (40 and 70 m/s) representing a captive bolt projectile, 5 impact depths (20, 25, 30, 40, and 55 mm), and 2 impact angles (normal to spine and normal to ribs).

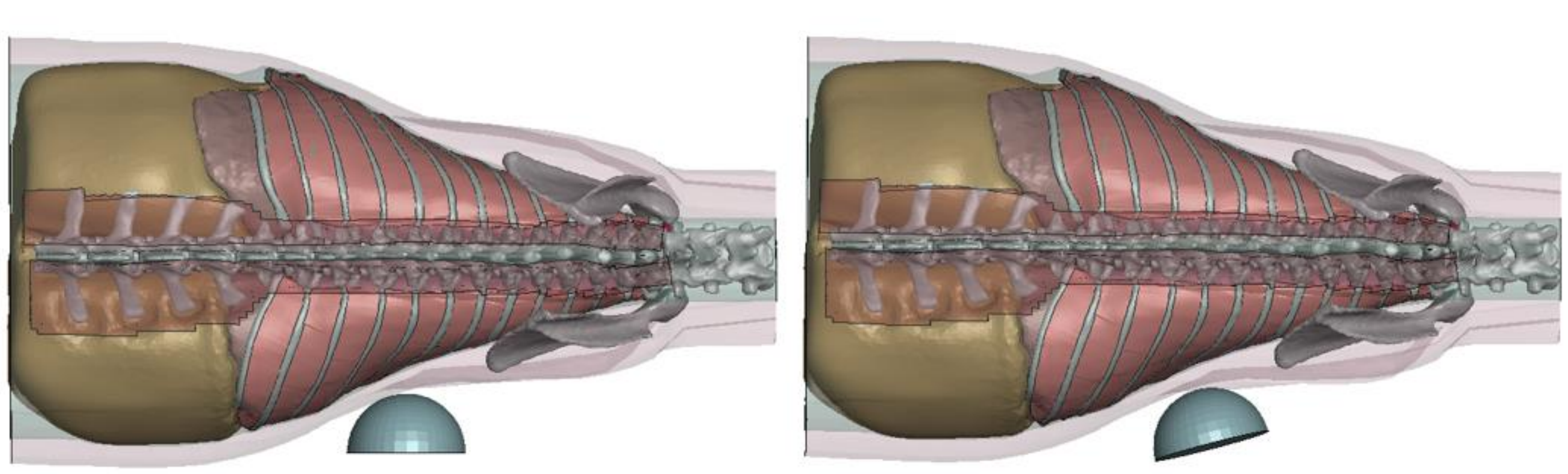

Figure 1: The model setup for the robustness testing simulations. Left: Normal to spine. Right: Normal to ribs.

- The first principal strain was analyzed for two boxes of lung tissue, one along each path of impact.

Results

The final meshed model met the GHBMC set standards for element quality [1]. The assembled model has a run time ratio of 9 min to 1 ms of simulation time using 40 cores. The model was found to be robust in the NPBI environment and all simulations normal terminated. Trends showed that contact force was not significantly affected by impact angle and increased with impact speed and depth (Figure 2). The strain analysis showed impact angle affects peak strain, and location of tissue effects time to peak strain (Figure 3). The peak first principal strain was higher for normal to rib impacts compared to the normal to spine impacts.

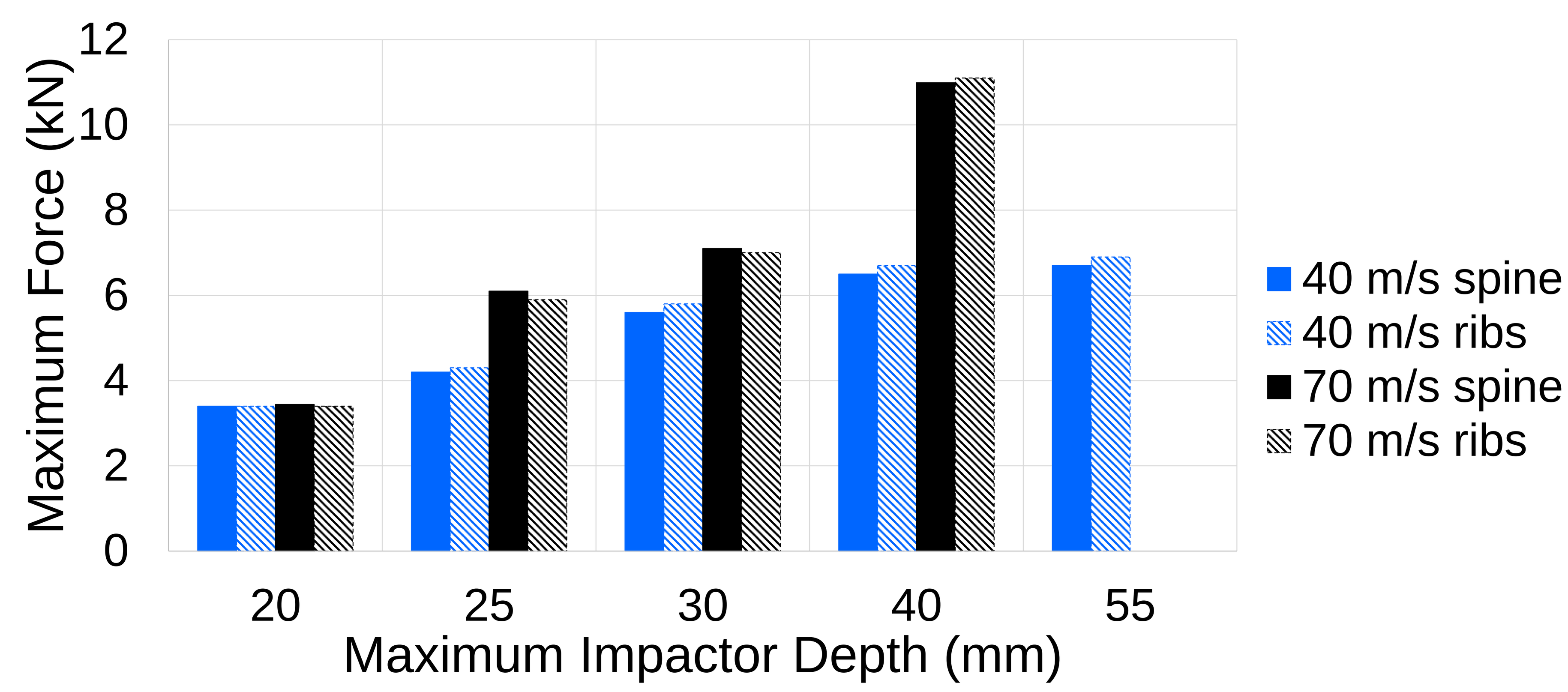

Figure 2: The peak force of each impact per the maximum depth of impact.

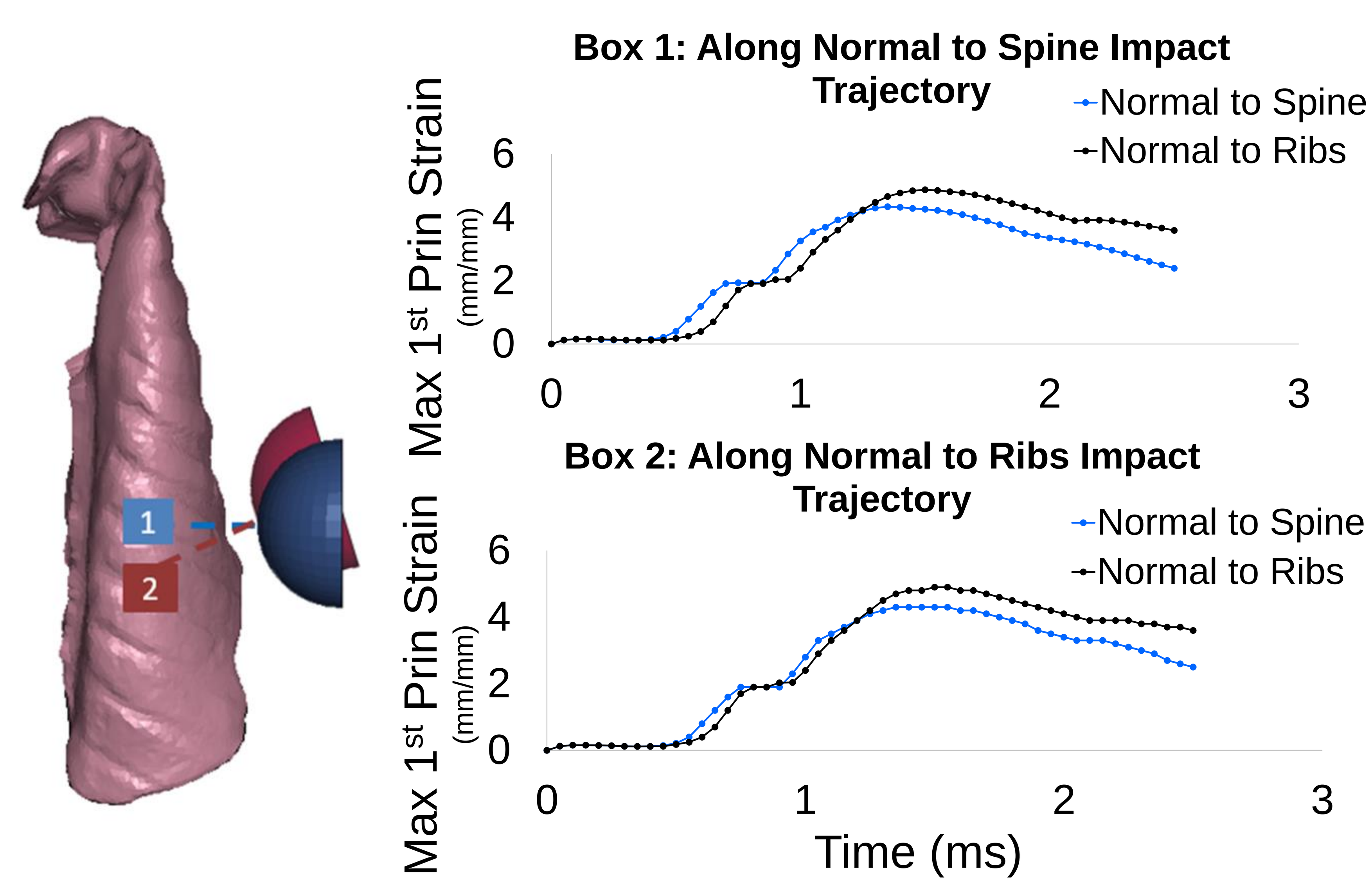

Figure 3: Exemplar 1st principal strain response for a 40 m/s 40 mm impact. Left: Location of boxes 1 and 2 used for the strain analysis. Right: Maximum first principal strain of lung tissue in the boxes over time.

Conclusions

The peak force values are within the same range as those observed in experimental testing by our collaborators at Temple University. These preliminary results show that the model developed is a reasonable tool for the assessment of NPBIs. The impact angle had no significant effect on the force response. All simulations, indicated a likelihood of pulmonary contusion based on Gayzik et al. in the two areas of lung tissue analyzed [2]. The peak strain was greater for the normal to ribs impact angle. This indicates that the angle of impact will affect injury severity of internal tissues even when the force response stays the same.

Next Steps

Future work will validate the model results against experimental impact data from ovine test subjects and develop computationally based injury metrics for injuries resulting from high rate NPBI.

Acknowledgements and References

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[1] Gayzik et al. 2011 [2] Gayzik et al. 2007