Penetration of Blast Fragments to the Thorax

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I. INTRODUCTION

In recent conflicts and terrorist attacks the most common source of injury to both military personnel and civilians has been the explosive device [1-3]. Due to its design, penetration by energised fragments is the most common wounding mechanism among the blast traumas [3-4]. The latest study on penetrating injury to UK military personnel [1] showed that the thorax was the most commonly injured region in fatalities (21% of 450 cases), and that treatments were often more complicated for cases where fragments hit bones and stayed inside the body. The aim of this study was to investigate the penetration of fragment-simulating projectiles (FSPs) to tissues of the thorax, namely the ribs, intercostal muscle, sternum and scapula, in order to identify the thresholds of impact velocity for penetration through these tissues.

II. METHODS

A 32 mm bore, single-stage gas gun system [5] was employed (Fig. 1(a)). The device could accelerate a sabot unit to a velocity of 20–600 m/s. A 0.78 g cylindrical FSP, 4.5 mm in diameter and 6.5 mm in length, was chosen for the study [5]. The FSP was mounted at the front of the sabot and separated from this by the sabot stripper construction upon entering the target chamber to impact the sample. High-speed photography was used to record the penetration and to measure the speed of the FSP at impact.

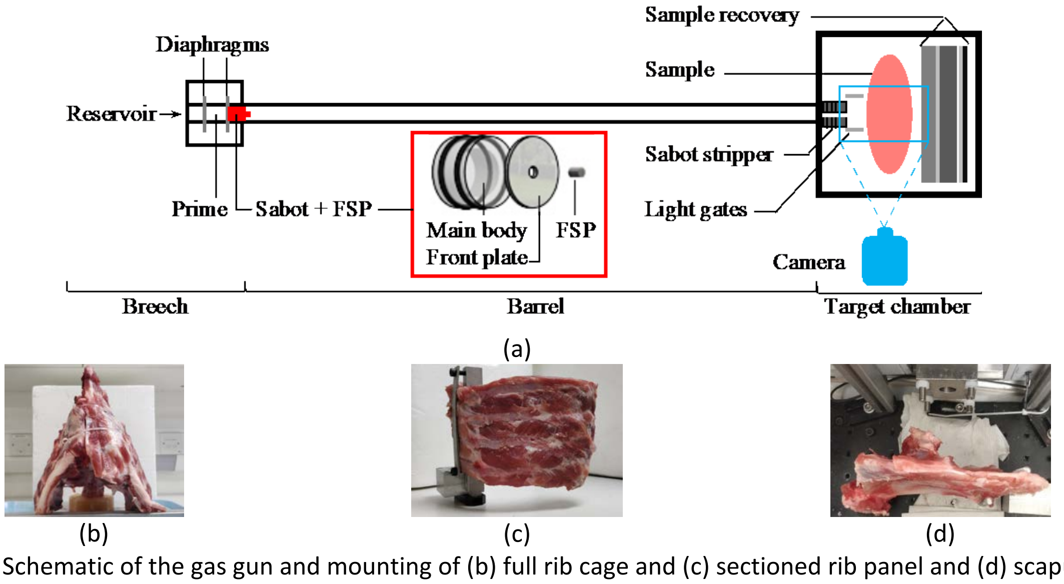

Fig. 1. (a) Schematic of the gas gun and mounting of (b) full rib cage and (c) sectioned rib panel and (d) scapula.

Rib cages and scapulae from skeletally matured pigs were used. All outer soft tissues were removed, leaving only intercostal muscles and the parietal pleura intact. The samples were fresh frozen at -20°C and thoroughly thawed prior to testing. The ribs were mounted either as (i) a whole rib cage (Fig. 1(b)) or as (ii) a sectioned panel (Fig. 1(c)) to check the sensitivity to the boundary condition. The flatter region of the ribs (30–70% of total length), which is closer to the human anatomy, was targeted. Sternums were tested in set-up (i) and scapulae were mounted so that their posterior surface faced the direction of impact (Fig. 1(d)). Post-impact, all samples underwent radiographic scanning to image the resultant fractures. The Weibull distribution, with penetration categorised as left-censored and no penetration as right-censored, was used for survival analysis.

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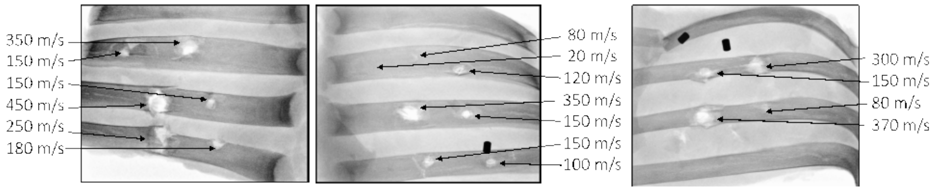
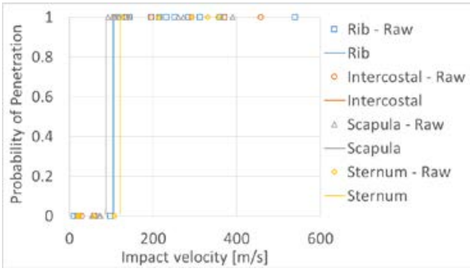
III. INITIAL FINDINGS

There was a total of 24 tests conducted on the rib bones, eight tests on the intercostal muscles, nine tests on the sternum, and 12 tests on the scapula, across two porcine specimens. Radiographs in Fig. 2(a) show examples of fracture patterns observed. These patterns were independent of set-up. All penetrations through bone produced the drill-hole fracture, which was generally observed to be larger in size for higher impact speeds.



(a)



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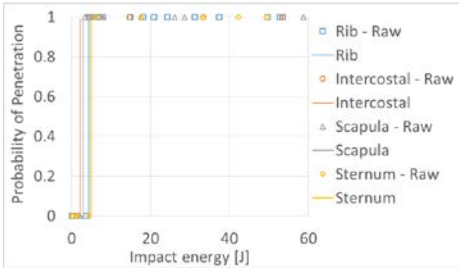

(c)

Fig. 2. (a) Exemplar radiographs of penetration by FSPs to rib bone in full (*left & middle*) and sectioned (*right*) set-up; (b) velocity-based and (c) energy-based risk curves for penetration of FSPs through different tissues.

The risk of penetration to each of the tissues tested as a function of the impact velocity and energy of the FSP is shown in Fig. 2(b&c). At 50% penetration risk, the speed (v_{50}) and energy (E_{50}) were 105 m/s – 4 J, 88 m/s – 2 J, 121 m/s – 5 J and 87 m/s – 3 J for rib bone, intercostal muscle, sternum and scapula, respectively.

IV. DISCUSSION

This study is the first to generate the risk of penetration for different tissues in the thorax. It is a step forward for the prediction of injury severity and for improving the design of protective equipment. The preliminary results show that the sternum is the most resistant thoracic tissue to penetration. Interestingly, the v_{50} for the scapula is very similar to that of the intercostal muscle, which is a soft tissue. The same resultant fracture patterns in both set-ups of the ribs show that the response of the rib bone is not very sensitive to the boundary condition as well as the rib level and position of the impact. This is likely due to the small size of the FSPs making the material properties more relevant than the global structural effects [6-7]. The residual velocity of FSPs after penetration will be investigated for predicting the risk to organs inside the rib cage.

The porcine model is a conventional choice for studies of trauma to the chest [8-10] as they have the same pattern and shape as those of humans, and skeletally mature porcine specimens share the common cortical bone Haversian tissue microstructure and density with human bone [11]. Currently, a 1:1 scaling factor is used, which needs to be confirmed or improved by adapting the experimental model on human cadaveric samples.

V. REFERENCES

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