Lung Injury Criterion for Behind Armour Blunt Trauma using Live Swine Tests

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I. INTRODUCTION

The current behind armour blunt trauma (BABT) performance assessment method is to measure the armour's depth of backface deformation into Roma Plastilina No. 1 clay. The methodology was based on goat tests conducted in the 1970s, with a recommendation of 44 mm depth of penetration in the clay. This metric has subsequently been used as the testing standard for both soft and hard body armour assessment and development [1]. Because the thoracoabdominal contents covered by the body armour are heterogeneous in terms of physiological function, mechanical responses to impact loading and other factors, a single metric at a chosen risk level (10% in this case) does not represent the tolerance of organs such as the lungs and liver at the same amplitude od deflection and injury probability level. The objective of this short communication is to develop lung injury criteria in the form of injury risk curves (IRCs) using a live animal model as a first step in the determination of tolerances to different thoracoabdominal organs.

II. METHODS

After obtaining institutional animal committee and sponsor approvals, swine were obtained from a vendor, acclimatised in the veterinary unit for 48 hours, and prepared to receive simulated BABT insult. Trachea tubes and intravenous lines were placed by the trauma surgeon following the induction of anaesthesia using Telazol and Xylazine. Pressure transducers were placed in the lungs and aorta. One transducer was guided into each lung through the trachea tube. To place the aorta transducer, a small incision was made in the neck to isolate a blood vessel routing to the aorta. The blood vessel was clamped on one end to allow for a small incision to be made to insert the transducer. The transducer was sutured to prevent movement and blood loss. Radiographic imaging confirmed transducer placement. Impact loading was applied to the supine-positioned animal using a custom indenter. Its design was based on the backface deformations from previous cadaver tests with hard body armour [2]. An accelerometer attached to the indenter recorded acceleration signals at 100 kHz and allowed the calculation of velocity and deflection time history profile data after filtering at 2 kHz. The viscous response was calculated from the velocity and normalised deflection time histories (based on chest depth at the impact location and along the impact axis). The peak magnitude of the combined response was termed as the viscous criterion [3]. Physiological parameters were monitored for six hours before euthanasia, and then autopsy was conducted. Injuries were graded as mild, moderate, or severe, using the American Association of Surgery for Trauma (AAST) scale, by the trauma surgeon author (LS). Injury risk curves were developed using parametric survival analysis for different potential candidate injury metrics. Non-injury and injury data were assigned as right and uncensored variables. The present short communication is focused on the peak viscous criterion [3]. The quality of IRCs was assessed for the 95% confidence interval bounds at 10%, 25%, 50%, 75% and 90% injury probability levels using the normalised confidence interval size (NCIS) [4]. The NCIS was defined as the width of the interval normalised to the mean value of the metric at the chosen risk level [4]. Two animals were used as control specimens that were not subjected to impact loading.

III. INITIAL FINDINGS

There were 24 live swine lung impacts. Each animal was impacted once. The two control animals did not sustain any injuries as observed at autopsy, indicating that injuries in the impact-tested animals were due to the mechanical BABT loading. No injury was observed in five of the impacted animals, while five, eight and six animals

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sustained mild, moderate, and severe lung injuries, respectively. The magnitude of the viscous criterion at the 25% risk level for these severities was 2.5 m/s, 3.5 m/s and 5.1 m/s, respectively. The mean viscous criterion injury probability curves for the three severities of lung injury are compared in Fig. 1. The qualities of the mild, moderate, and severe risk curves were assessed at the 10% risk level as marginal, fair, and fair; at the 25% risk level as fair, fair, and good; and at the 50% risk level as fair, good, and good. The NCIS data at different risk levels are also shown in Fig. 1.

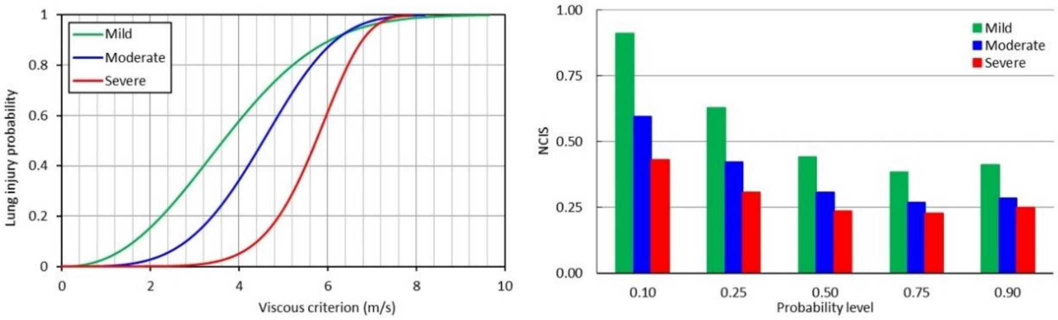

Fig. 1. The mean viscous injury criterion risk curves for the mild (green), moderate (blue), and severe (red) lung injuries.

IV. DISCUSSION

Recognising that the original authors in the 1970s reported that any conclusions from their studies were based on limited test data and should be considered as "provisional" [5], to the best knowledge of the current authors, injury risk curves focused on individual thoracoabdominal organs are not available; this is the first study to develop lung injury criteria for three severities: mild, moderate, and severe. Live swine were chosen due to their applicability to thoracoabdominal organ injuries and the ability to monitor injury physiology, a critical parameter for organ injury development. This contrasts with skeletal injuries, such as rib or spine fractures, that are not temporal. Injury risk curves were presented using the viscous criterion because it represents the viscous nature of the trauma to internal organs in a live animal model [4]. It is considered as an underlying injury mechanism to soft tissues in impact loading scenarios. Original goat studies used binary logistic regression techniques without reporting confidence interval bounds [5]. In contrast, the present study developed injury risk curves using survival analysis, as it accounts for data censoring, is recommended by the International Standards Organization, and is used in automotive and other disciplines for developing standardised crashworthiness test methods using surrogates [6]. While not described here, the use of the Weibull distribution as the optimum probability function for all severities in the present study was based on the corrected Akaike information criterion, eliminating a priori assumption on the distribution. This process added to the statistical rigour to the analysis. While these results are based on a widely used live animal model, on single-impact loadings applied using an indenter that simulated the backface deformations, and using the AAST hepatic scoring system, additional studies are needed to include additional potential backface deformation profiles to confirm the validity of the risk curves. This process adds to the robustness and generalisability of BABT lung injury criteria for enhanced Warfighter safety and the assessment and development of current and future body armour against emerging threats across the globe. To cover additional soft tissues in the thoracoabdominal cavity, a similar methodology can be used for other organs, such as the liver, heart, spleen, and kidney.

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VI. REFERENCES

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