Behind armor blunt trauma (BABT) indenter simulating high-velocity impacts from rifle rounds on hard body armor

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Background

Body armor provides protection against gunshot wounds for both civilian and military personnel. When body armor deforms to defeat an incoming round, the backface deformation of the armor can produce high rate loading of the thorax, injuring the ribcage and internal organs. To improve body armor design without diminishing vital protection or increasing user burden, more accurate thorax impact behavior and injury criteria are needed, simultaneously increasing the biofidelity of finite element models. Criteria for assessing BABT risk rely on studies determining backface deformation in clay or ballistic gelatin; neither have direct correlation to human or animal models and are insufficient for developing accurate thoracic BABT injury criteria.

Objective

In this study, we developed a repeatable, non-destructive test setup to quantify the effects of behind armor blunt trauma (BABT) in vivo using pigs or other human surrogates. The setup using an indenter will allow us to obtain thorax dynamics, thorax material properties, and determine injury risk curves for rib fractures, bruising, and soft tissue injuries in future studies.

Methodology

Flash x-ray images of backface deformation in hard body armor during rifle round impact (Bass et al., 2006 and Sarron et al., 2000) provided depth and diameter measurements, which were used to create an indenter machined out of polycarbonate (mass: 0.214 kg, diameter: 100 mm). The indenter with onboard instrumentation (Endevco 7270; Slice Nano, DTS) was propelled using high pressure helium gas to deliver impacts simulating BABT. Four tests of increasing velocity (22-54 m/s) were performed on two live anesthetized pigs, impacting the upper thorax and the lower thorax bilaterally. Thorax impact energy varied from 104 J to 624 J, while indenter peak acceleration upon impact varied from 3,739 g to 26,740 g. Force was obtained by multiplying indenter mass by acceleration. Displacement during impact was obtained from double integration of the measured acceleration and verified using high speed video images. Force-displacement behavior was visualized for each impact. Bone fractures and soft tissue injuries were assessed with a post-test necropsy and micro CT scans.

Results and Conclusions

Peak force experienced during impact varied from 10.5 kN at 1 mm displacement during the 104 J impact to 56 kN at 3.2 mm displacement during the 624 J impact. Multiple rib fractures occurred for all impacts above 233 J, and a 104 J impact caused broken ribs in one pig but not in the other. All rib fractures were non-displaced and did not penetrate the pleura. Liver and lung contusions occurred in impacts above 233 J, and lung contusion also occurred in the 104 J impact with broken ribs. Observed injuries are similar to reported in-field conditions following BABT. This test methodology provides a repeatable and robust instrumented impact scenario representative of BABT.