19th International Symposium of Ballistics, 7–11 May 2001, Interlaken, Switzerland

THE DEVELOPMENT OF A PHYSICAL MODEL OF NON-PENETRATING BALLISTIC INJURY

Surgeon Lieutenant Commander L Cannon Royal Navy, W Tam

Biomedical Sciences, DERA Porton Down, Salisbury, Wilts, SP4 OJQ, UK

Behind armour blunt trauma (BABT) is the injury inflicted to the torso as a consequence of energy transfer from rigid body armour defeating high-energy projectiles. This study has 2 aims: (1) to provide the biomechanical basis of chest wall motion behind armour that has defeated a bullet (which is undetermined as yet); and (2) the development and validation of a physical model which mimics the motion characteristics of an eviscerated pig thorax. Eviscerated pig thoraces were mounted on a novel laser deformation sensor array system (DSA) to determine absolute displacement with time (and subsequent velocity and acceleration profiles). The physical model consisted of a silicone rubber 'chest wall' mounted in the DSA. Energy loading comprised 7.62 mm bullets (3 kJ) fired against ceramic body armour applied to the lateral thorax. No statistically significant differences were detected (for acceleration, velocity and displacement) between the pig and physical models.

INTRODUCTION

Behind armour blunt trauma (BABT) is the injury inflicted to the torso and its contents as a consequence of energy transfer from rigid body armour defeating high-energy projectiles. Although the armour may stop the actual penetration of the projectile through the armour, the energy deposited in the armour by the retarded projectile may be transferred through the armour backing and body wall. It may produce serious injury to the thoracic and abdominal contents behind the plate. Due to the increasing deployment of high-energy weaponry against troops and the development of personal armours designed to defeat these threats, NATO believes the incidence of BABT will rise in future conflicts. As a result, a NATO Task Group has been instigated to study its mechanics and effects [1] and includes our institute.

Much of the available knowledge of blunt injury mechanisms has been generated by the automobile industry. The thoracic injury mechanisms following automobile accidents are characterised by low speed, large mass impacts transferring energy to the chest over a comparatively long time period. This is in direct contrast to ballistic impacts on ceramic plates, but nevertheless some of the biophysical data from research aimed at reducing the incidence and severity of thoracic trauma form automobile accidents provides insight to the dynamic response of the chest to impact.

Organ damage seen in BABT arises as a result of pressure waves produced by the initial impact of the bullet on the plate and by secondary chest wall motion. The contact of the bullet on the face of the ceramic plate generates a very short duration stress wave [2]. This wave propagates through the plate and its backing, and couples directly into the body. This is an extremely fast event with no significant gross motion of the plate or body wall. The subsequent chest wall motion has not been determined.

The injurious biomechanical parameter responsible for the majority of organ damage in BABT remains, therefore, elusive. Due to the differing impact mechanics of automobile accidents as previously mentioned, it seems likely that the mechanisms of injury in BABT are different. Blast injuries share similarities with BABT in terms of the rapid exchange of energy to the chest and the pathological appearance of the lungs following injury. The peak acceleration the body wall has been shown to be the best correlate for lung injury following blast injury, where a threshold of 10 kms^{-2} has been found [3]. A good correlation was achieved between peak chest wall acceleration and the degree of haemorrhage and oedema in the lung.

Currently, the ranking and quality control for BABT of soft and rigid body armours relies on a poorly validated model of depth of clay indentation [4]. This model takes no account of the dynamic aspects of energy loading but no better system exists, as yet, to replace it. While the deficiencies of this standard are widely recognised, it does at least offer the commercial developers of armours a performance target to reduce the trauma from localised thoracic wall deflection.

This study has 2 aims: (1) to provide the biomechanical basis of chest wall motion behind armour that has defeated a bullet; and (2) the development and validation of a physical model that mimics the motion characteristics of an eviscerated pig thorax model.

MATERIALS AND METHODS

Six pigs were used. The model made use of eviscerated pig thoraces that allowed recording and filming of the motion of the inner thoracic wall. The pigs were eviscerated via the abdomen, where the thoracic and abdominal contents were removed leaving the bony structures and thoracic wall intact. Uniaxial accelerometers were mounted on the pleural aspect of ribs 7, 8 and 9 on the right lateral side via small thoracotomies. The eviscerated thoraces were mounted on the DSA to determine displacement with time (and subsequent velocity and acceleration profiles).

The physical model of the chest wall was developed from the results of finite element modelling incorporating data from blast as well as blunt projectile impacts. It consisted of a silicone rubber ‘chest wall’ mounted in the DSA (Fig. 1). Four firings were conducted against this model.

Energy loading comprised 7.62 mm bullets (3 kJ) fired against commercially available ceramic body armour applied to the lateral thorax.

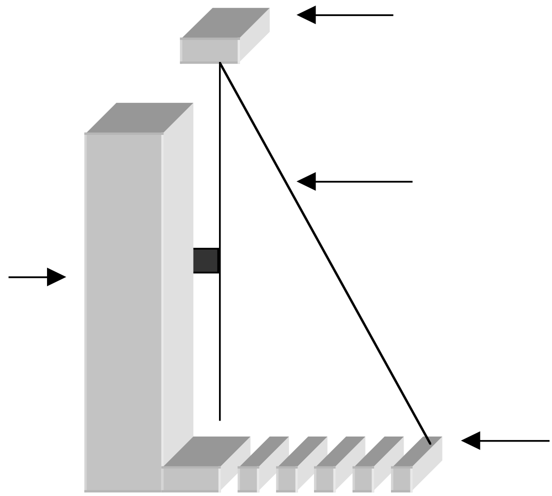

Figure 1. Schematic diagram of the physical model.

RESULTS

The peak biomechanical parameters for the pig thoraces and physical model are shown in Table 1. The results obtained from the physical model proved extremely repeatable with little variation.

Table 1. Motion characteristics of pig and physical models (means of maximum values obtained from accelerometer closest to point of impact and the DSA). The DSA is unable to provide data on peak displacements in the eviscerated model.

Parameter	Eviscerated model		Physical model
	Accelerometer	DSA	DSA
Peak acceleration (kms^{-2})	179	210	163
Peak velocity (ms^{-1})	12.6	25	31
Peak displacement (mm)	26.8		31.5

Using analysis of variance, no statistically significant differences were detected between the pig and physical models. The peak values of acceleration provided the best biomechanical correlate with rib fractures (r=0.78) and lung injury (r=0.89).

DISCUSSION

The importance of an eviscerated thorax model is that it allowed the use of a separate dynamic sampling system (the DSA) to complement the results obtained from the accelerometers and allowed a direct comparison with the results obtained from the physical

Home
Table of Contents

model. In other experiments, the biomechanical responses of eviscerated thoraces were compared against intact pigs and the two models were shown to behave similarly. This implies that the presence of intrathoracic organs does not influence the early motion of the chest wall *at these loadings* and therefore the use of eviscerated thoraces is vindicated.

The peak accelerations were greatly in excess of the threshold for lung injury as determined in blast lung (10 kms^{-2}). This is in agreement with the lung pathology seen following experimental BABT in live animal experiments. The biomechanical behaviour of the physical model is very similar to that of porcine eviscerated thoraces, particularly so for peak accelerations. Future planned experiments using anaesthetised animals will attempt to correlate these biomechanical parameters with injury production. The BABT physical model may then be in a position to replace the current armour testing system. A validated physical model also has the wider implications of animal replacement, elimination of biological variance and cost advantages.

REFERENCES

1. Knudsen PJT. “Conclusions of STBA”. *In Proceedings of the 3rd Meeting of the Specialist Team on Body Armour.* NATO Unclassified. San Diego, USA, 23–25 April 1996
2. van Bree JLMJ, van der Heiden N. “Behind armour pressure profiles in tissue simulant”. *In Proceedings of the Personal Armour Systems Symposium 1996.* Colchester UK. 3–6 Sept. 1996
3. Cooper GJ. “Protection of the lung from blast overpressure by thoracic stress wave decouplers”. *J Trauma.* 40(3): S105–110 1996
4. National Institute of Justice. Ballistic Resistance of Body Armour – NIJ Standard 0101.03. April 1987