COMPUTATIONAL MODELING FOR EVALUATING THE EFFECTIVENESS OF PROTECTIVE PLATES IN NON-PENETRATING BALLISTIC IMPACTS

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Introduction

A ballistic protective plate (BPP) is standard military equipment that reduces the risk of severe injuries in the torso area which are common in combat environments, being approximately 25-30% of all injuries [1].

Non-penetrating impacts of bullets or other ballistic threats such as blast explosions, shrapnel, or shrapnel shells with the BPP are accompanied by rapid and immediate deformations of the armour and underlying tissues. These are translated to mechanical energy absorbed in the tissues behind the armour, causing the injury known as 'behind armour blunt trauma' (BABT) [2].

That absorbed energy takes the form of pressure waves that propagate through the tissues, including deep tissues that are not in direct contact with the gear, resulting in rapid deformations, stretching and collapse of the tissues and associated cell and tissue death [3-4].

To date, there is no effective and cost-effective procedure for rapid testing of BPP designs. The objective of this study was to develop a novel, anatomically-accurate, finite element modelling framework as a decision-making tool to evaluate and rate the biomechanical efficacy of BPPs in protecting the torso from battlefield-acquired non-penetrating impacts.

Methods

To evaluate the biomechanical efficacy of BPPs designed for protecting the torso from a battlefield-acquired non-penetrating impact, a three-dimensional (3D), anatomically-accurate model of the torso was developed. The geometry of the upper-body model which we have developed is based on 267 transversal images of the torso from the Visible Human Project anatomical database [5].

To simulate a blunt impact with a BPP two plate types were modelled, representing generic designs of threat-level III and IV plates (according to NIJ Standard–0101.06). A 5.56 mm bullet was modelled as well as the projectile hitting the plates. We used the realistic dimensions, physical and mechanical characteristics of the plated and the bullet.

The constitutive laws and mechanical properties of all the tissue components were considered to represent homogenous-isotropic material behaviours, and specific parameter values were adopted from the literature. The material of the BPPs was Kevlar-29, assumed to be orthotropic elastic. The 5.56 mm bullet material was 4340 Steel.

Results

The results indicated that plate level-IV induces greater tissue strains and stresses post the ballistic impact; this is due to the fact that plate level-IV is larger, thicker and heavier than plate level-III, and therefore, its kinetic energy is higher and so is the shock wave which is transferred to the tissues behind plate level-IV.

Discussion

We have shown here, using a highly advanced FE modelling framework, that contrary to a false premise, a thicker and heavier BPP does not necessarily protect all underlying tissue structures better than a thinner, lighter plate.

Our modelling provides a versatile, powerful testing framework for both industry and clients of BPPs, at the stages of prototype design, prior to manufacturing and procurement processes, or for quantitative standardized evaluations of candidate products in purchasing decisions and bids.

References

[1] N. R. Koreerat and C. M. Koreerat, "Prevalence of Musculoskeletal Injuries in a Security Force Assistance Brigade Before, During, and After Deployment," Mil. Med., vol. 186, no. Supplement_1, pp. 704–708, 2021.

[2] D. Drobin et al., "Electroencephalogram, circulation, and lung function after high-velocity behind armor blunt trauma," J. Trauma - Inj. Infect. Crit. Care, vol. 63, no. 2, pp. 405–413, 2007.

[3] L. Cannon, "Behind Armour Blunt Trauma - an emerging problem," J. R. Army Med. Corps, vol. 147, no. 1, pp. 87–96, 2001.

[4] J. Van Bree and N. Van der Heiden, "Behind armour blunt trauma analysis of compression waves," in Personal Armour Systems Symposium 1998 (PASS98), 1998.

[5] M.J. Ackerman. The Visible Human Project. Proceedings of the IEEE 86, 504–511, 1998.

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Keywords

Thoracic injury, Finite element modelling, Behind armour blunt trauma, Protective plate, Ballistic impact