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British Journal of Oral and Maxillofacial Surgery 51 (2013) 47–51

BRITISH Journal of Oral and Maxillofacial Surgery

www.bjoms.com

Developmental framework to validate future designs of ballistic neck protection☆

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Accepted 4 March 2012
Available online 27 March 2012

Abstract

The number of neck injuries has increased during the war in Afghanistan, and they have become an appreciable source of mortality and long-term morbidity for UK servicemen. A three-dimensional numerical model of the neck is necessary to allow simulation of penetrating injury from explosive fragments so that the design of body armour can be optimal, and a framework is required to validate and describe the individual components of this program. An interdisciplinary consensus group consisting of military maxillofacial surgeons, and biomedical, physical, and material scientists was convened to generate the components of the framework, and as a result it incorporates the following components: analysis of deaths and long-term morbidity, assessment of critical cervical structures for incorporation into the model, characterisation of explosive fragments, evaluation of the material of which the body armour is made, and mapping of the entry sites of fragments. The resulting numerical model will simulate the wound tract produced by fragments of differing masses and velocities, and illustrate the effects of temporary cavities on cervical neurovascular structures. Using this framework, a new shirt to be worn under body armour that incorporates ballistic cervical protection has been developed for use in Afghanistan. New designs of the collar validated by human factors and assessment of coverage are currently being incorporated into early versions of the numerical model. The aim of this paper is to describe this developmental framework and provide an update on the current progress of its individual components.

Keywords: Neck; Combat; Explosive; Fragment; Modelling; Surface wound mapping; Body armour; Skin; Muscle

Introduction

There has been a sustained increase in the incidence of wounds to the head, face, and neck in proportion to injuries to the rest of the body sustained by both UK and US forces in conflicts from the 20th to the 21st century.[1–6] Reasons for this increase include the effectiveness of modern body armour in reducing thoracoabdominal injury,[1,3,5,7,8] together with a higher proportion of injuries from explosive devices.[1,2,5,6] Although the proportion of wounds to the face and head has increased equally for both nations,[3] UK forces have experienced more combat neck injuries their US counterparts.[1,5,6] This difference has been ascribed to the greater use of ballistic neck collars by US servicemen[5,9] than their UK counterparts.[10] The area of exposed neck when a ballistic neck collar is not worn with body armour is clearly shown in Fig. 1.

To develop new methods of protecting the neck from combat injury, an experimental framework has been designed (Fig. 2). This will provide a pathway from recognition of the

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0266-4356/$ – see front matter
doi:10.1016/j.bjoms.2012.03.001

Fig. 1. A British serviceman in Afghanistan wearing Mark IV OSPREY body armour without a neck collar.

underlying pathological mechanisms to developing potential new designs of neck collar, the effects of which could be numerically modelled before implementation. The aim of this review paper is to describe this framework and provide an update on its current progress.

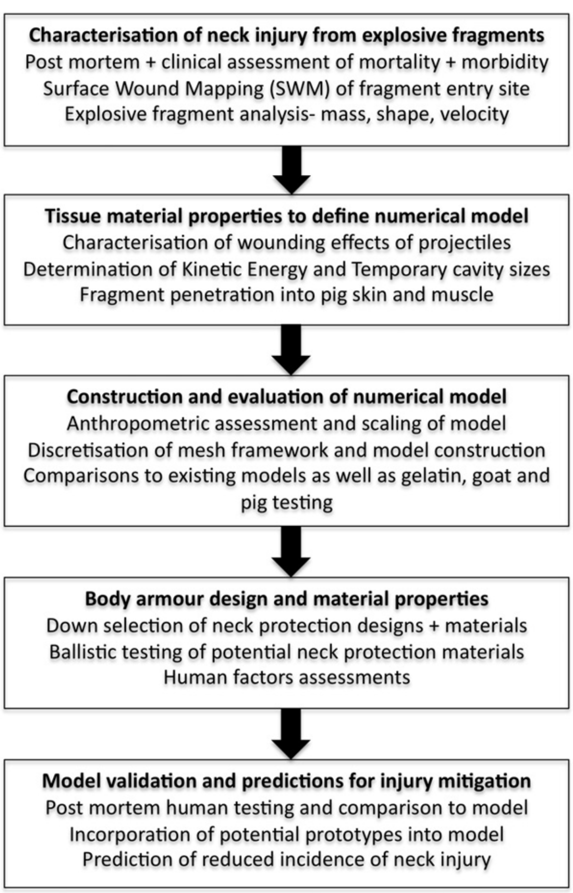

Fig. 2. Proposed flow diagram from characterisation of initial injury to validation of the model.

Material, methods, and discussion

Ethical considerations

In line with current Defence Medical Services (DMSs) policy, the DMS Research and Ethics committee approved this research. All data about patients have been anonymised. Permission has been given by Her Majesty's Coroners with jurisdiction over the investigation of deaths of service personnel.

Characterisation of combat injury to the neck from explosive fragments

The neck contains vital structures with little inherent anatomical protection so that low energy threats can often be fatal.[6] An analysis of all UK neck injuries sustained between 1 January 2006 and 31 December 2010 showed that 79% of neck wounds were caused by explosions, with an associated mortality of 41%.[5] Of deaths, 85% were caused by damage to either the carotid and vertebral arteries, or the internal jugular veins, with the remainder the result of injuries to the spinal cord. The proposed mathematical model of neck injury should therefore incorporate these four neurovascular structures in anatomically correct relations, both to one another and to the surface of the skin, for the simulation of penetrating explosive fragments.

Analysis of hospital necropsy records allowed accurate surface wound mapping, which is the process by which the sites of entry and exit of ballistic missiles are charted pictorially through either two-dimensional anatomical diagrams or a three-dimensional computer-based model. However, despite its potential importance in the evaluation of the potential coverage of new or improved designs of body armour, only three papers have been published on the subject, to our knowledge.[7,11,12]

After an open competition, a single software designer won the contract to design the prototype program for Surface Wound Mapping with the long-term aim of incorporating it into the United Kingdom Joint Theatre Trauma Registry. This software will allow the entry and exit wounds of both explosive fragments and gunshot wounds to be plotted on to a three-dimensional human figure (Fig. 3). When information about exit wounds is not available, analysis of detailed necropsy records in conjunction with ballistic reports from the scene of injury will in many cases make it possible to calculate the probable shot-line of the projectile.

Although explosive fragments are intermittently recovered from injured personnel, we have a limited sample because of difficulties in identifying them. This sample may be large enough to be statistically valid for the body as a whole, but is too small for analysis of those causing injury to the neck alone. Supplementation of the sample through retrospective analysis of computed tomograms (CTs) may allow characterisation of those retained fragments that have not been removed. Fragments should be divided into groups