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Clinical and post mortem analysis of combat neck injury used to inform a novel coverage of armour tool

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ABSTRACT

Introduction: There is a requirement in the Ministry of Defence for an objective method of comparing the area of coverage of different body armour designs for future applications. Existing comparisons derived from surface wound mapping are limited in that they can only demonstrate the skin entry wound location. The Coverage of Armour Tool (COAT) is a novel three-dimensional model capable of comparing the coverage provided by body armour designs, but limited information exists as to which anatomical structures require inclusion. The aim of this study was to assess the utility of COAT, in the assessment of neck protection, using clinically relevant injury data.
Method: Hospital notes and post mortem records of all UK soldiers injured by an explosive fragment to the neck between 01 Jan 2006 and 31 December 2012 from Iraq and Afghanistan were analysed to determine which anatomical structures were responsible for death or functional disability at one year post injury. Using COAT a comparison of three ballistic neck collar designs was undertaken with reference to the percentage of these anatomical structures left exposed.
Results: 13/81 (16%) survivors demonstrated complications at one year, most commonly upper limb weakness from brachial plexus injury or a weak voice from laryngeal trauma. In 14/94 (15%) soldiers the neck wound was believed to have been the sole cause of death, primarily from carotid artery damage, spinal cord transection or rupture of the larynx. COAT objectively demonstrated that despite the larger OSPREY collar having almost double the surface area than the two-piece prototype collar, the percentage area of vulnerable cervical structures left exposed only reduced from 16.3% to 14.4%.
Discussion: COAT demonstrated its ability to objectively quantify the potential effectiveness of different body armour designs in providing coverage of vulnerable anatomical structures from different shot line orientations. To improve its utility, it is recommended that COAT be further developed to enable weapon and tissue specific information to be modelled, and that clinically significant injuries to other body regions are also incorporated.

Introduction

The introduction of individual body armour has resulted in significant reductions in the incidence and severity of wounds sustained by soldiers on combat operations in the modern age [1–10]. However there is a constant drive to develop novel methods of providing protection as well as to refine existing designs of body armour [9]. In order to objectively compare the potential effectiveness of future personal armour systems, the UK Ministry of Defence requires injury models capable of representing with high accuracy both the underlying vulnerable anatomical structures as well as the individual coverage of personal armour. However, existing injury models lack the fidelity required to make these comparisons [9]. An interim approach has been to develop more enhanced surface wound mapping (SWM), a method by which the entry wound location can be overlaid on different body

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armour designs. This demonstrated the potential utility of a technique in which any type of armour design could be three dimensionally scanned and objective comparisons made of the area of coverage provided by an armour design. However SWM can only represent the skin surface and requires accurate knowledge of both the wound location and the trajectory of the projectile, both of which are often not known [4].

A desired output would be an injury model that can accurately represent the penetration of a ballistic projectile (bullet or explosive fragment) through different ballistic protective materials and accurately predict the resultant area of permanently damaged tissue for different tissue types (the permanent wound tract). Such a model, based upon data from a high fidelity finite element (FE) approach is currently under development [9]. However actual realisation of this model is many years away as many of the algorithms required to populate it do not currently exist and will require new experimental research. In addition the time required to run each FE analysis (approximately one day per simulation) and immense computing power required limit this finite element approach for the time being to a limited number of locations within the United Kingdom [9].

The Coverage Of Armour Tool (COAT) is a newly developed geometrical analysis capability designed to objectively compare the ability of different designs of body armour to cover vulnerable anatomical structures (Fig. 1). It is based upon the 'Zygote' human model which was developed by Zygote Media Group, Inc. The model was provided as a mesh of surfaces representing all anatomical structures down to the smallest named nerves and vessels, having originally been derived from Computed Tomography (CT) scans of healthy volunteers [9]. In addition any design of body armour can be incorporated and overlaid onto these anatomical structures, either by generating a three-dimensional laser scan or importing a manufacturers Computer Aided Design (CAD) file.

COAT uses the concept of a 'shot-line' analysis, meaning that projectiles are assumed to be fired from outside the body and pass through the body in an infinitely thin straight line. A mesh of these shot lines, generally with 2 mm spacing between them, is superimposed over the body area being examined (e.g. the neck) in different angulations about the subject in the horizontal (azimuth) and vertical (elevation) planes. For example in the horizontal plane, 0° corresponds to a shot-line originating from in front of the body, 90° to a shot-line from the subject's right side, 180° to shot-line from behind and 270° to shot-lines originating from the subject's left side. In the vertical plane, 0° represents the shot-line being directed horizontally and −90° as if the projectile was directed from the ground going directly upwards through the subject (Fig. 2).

As COAT works by ascertaining the percentage exposed of anatomical structures provided by different designs of personal armour, it is important to differentiate which structures actually require protection as many anatomical structures are neither responsible for mortality or morbidity. The inclusion of all anatomical structures within the body region being analysed by COAT would merely result in those designs of body armour with the greatest surface area having the most effective coverage. The neck has previously been identified as a priority area for developing new methods of protection [11]. Prior to February 2014, the UK military OSPREY body armour system provided two sizes of ballistic neck collar (half and full). Neither size was liked by soldiers and both were rarely worn, resulting in potentially preventable neck injuries. Significant resources had been implemented in developing neck protection prototypes for ergonomics assessments to potentially replace these collars [12,13]; these prototypes could therefore be used to demonstrate the utility of COAT compared to previous analyses such as SWM [12,13]. The aim of this research was therefore to analyse all combat neck wounds to determine which anatomical structures were responsible for death and morbidity and utilise this knowledge to compare armour designs within COAT.

Method

Hospital and post mortem record analysis

The Joint Theatre Trauma Registry (JTTR) was used to identify all neck injuries sustained by UK military personnel in Iraq and

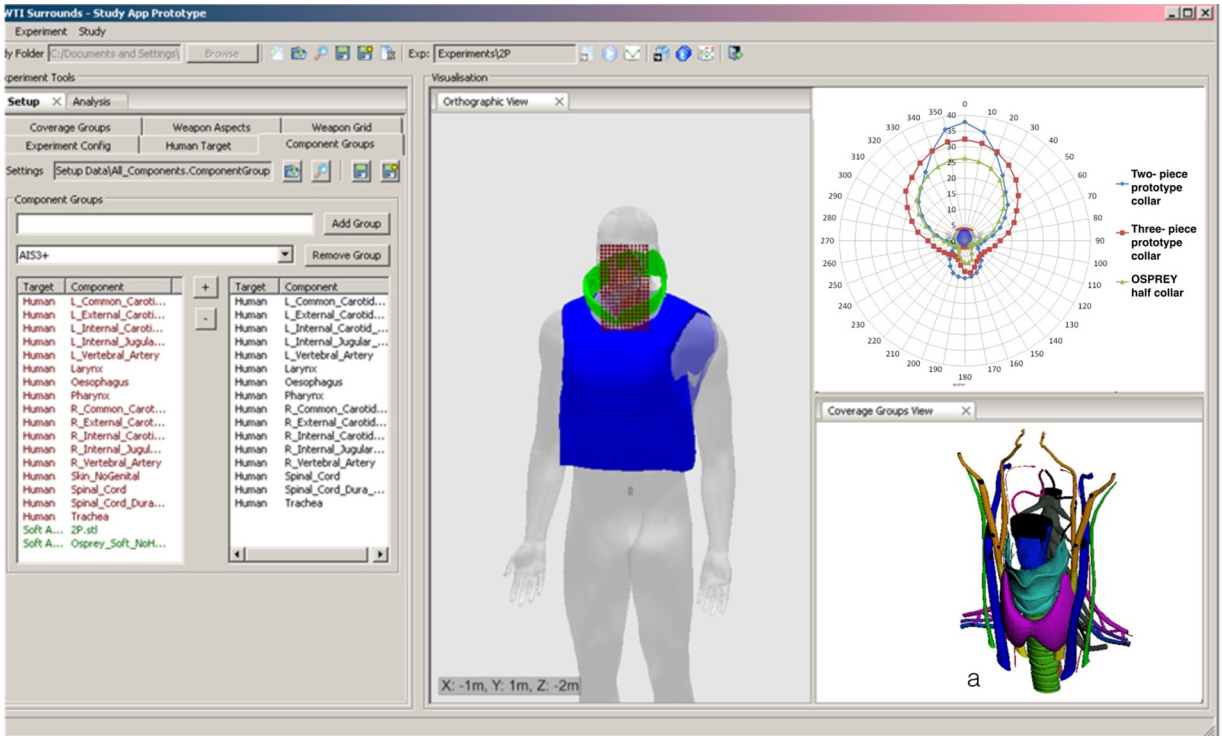

Fig. 1. A screenshot of the coverage of armour tool being used to objectively determine the coverage provided by a ballistic neck collar.