

<b>Institution: Imperial College London</b>
<b>Unit of Assessment: 15 (General Engineering)</b>
<b>Title of case study: Engineering a reduced incidence and severity of blast injury</b>
<p><b>1. Summary of the impact</b> (indicative maximum 100 words)</p> <p>Recent conflicts in Iraq and Afghanistan have exposed military personnel to improvised explosive devices and anti-vehicle mines. These cause complex lower limb injuries that frequently lead to long-term disability. From 2008, the Centre for Blast Injury Studies and its forebear, the Imperial Blast Research Group, both led by Bioengineering, have conducted multidisciplinary studies into the effects of blast on physiological systems. The research has led to changes in the posture and placement of personnel in Army vehicles, with significant impact on casualties. It informed the policy of Dstl concerning floor mat design and the policy of a NATO Task Group concerning standards for accepting battlefield vehicles in 2013. Mitigating effects of different boots have been characterised on behalf of Army procurement. Research into treatment has, since 2012, altered assessment criteria for, and timing of, amputations following heel injury, with consequent reduction in pain and futile surgery. It has also changed clinical practice for pelvic injuries in Afghanistan and major trauma centres; the new procedures are taught on military trauma courses. Finally, the research is currently being used in the US\$80M commercial development of military crash test dummies</p>
<p><b>2. Underpinning research</b> (indicative maximum 500 words)</p> <p>The Centre for Blast Injury Studies is led by Professor Anthony Bull, Professor Jon Clasper and Dr Spyros Masouros from the Department of Bioengineering. It emerged in 2011 from the Imperial Blast Research Group, established in 2008 and also led by Bioengineering, which initiated some of the research and impact described below; they are considered together in the following. CBIS is a collaboration between engineers, scientists and clinicians who study blast injury biomechanics, blast biology and therapeutics, and the engineering design of blast force protection. Collaborators have been drawn from all three Faculties at Imperial as well as the Shock Physics Group at Cambridge, the Royal Centre for Defence Medicine in Birmingham, and the Defence Science &amp; Technology Laboratory (Dstl). Having military clinicians working with engineers and scientists makes it possible to look not just at physical or biological effects of blast, but at the two together. CBIS research focuses on effects of improvised explosive devices (IEDs), which are the most prevalent threat to vehicle-borne servicemen in Iraq and Afghanistan. Clinical observations and computational and physical models of blast injury [e.g. 1] are used to replicate and understand patterns of injury. In all the examples presented here, research was published between 2011 and 2013, with the senior author and at least one other author coming from Bioengineering.</p> <p>Whilst there have been a large number of studies documenting the injury patterns resulting from an explosion, CBIS has pioneered fundamental investigation into the mechanical and physical processes which result in bone fracture, and into the effects of the subject's environment - free-field <i>versus</i> in vehicle or in cover. Analysis of field data showed significantly increased rates of lower limb injuries in survivors in the enclosed group [2]. Posture and position within a vehicle also affected the pattern and severity of injury. A key finding was that the predominant mechanism is bodily displacement of the casualty or impact against solid structures, with severe axial loading to the lower extremity being a characteristic cause of injuries [2]. CBIS derived a set of 'design principles' for vehicle protection by examining 2,212 incidents where civilians in vehicles were affected by landmines [3]. CBIS research has also examined the utility of different measures of</p>

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protection in vehicles. Testing methods have also been examined. Current NATO injury thresholds for anti-vehicle mine tests were extrapolated from automotive injury data obtained using the Abbreviated Injury Scale (AIS). CBIS staff compared this score with one that is specific to the lower limb – the Foot and Ankle Severity Scale (FASS) - for 63 casualties of under-vehicle explosions and showed that FASS is a better predictor than AIS of injury outcome.

CBIS research has examined the likely influence on injury of different types of battlefield footwear. The high complication rate arising from calcaneal (heel) fractures motivated a study of the efficacy of two commonly used combat boots in mitigating them. Boots were subjected to energies relevant to blast rather than - as in previous work - energies relevant to heel strike during running. Clear differences between the two boots were seen.

CBIS has also conducted research into the progression and treatment of injuries. One study used audited trauma registry data, prospectively collected from 1/2006 to 12/2008, to select casualties who sustained calcaneal fractures [4]. Patterns of injury, trauma radiographs and rehabilitation records were examined, the first such study since WWII. Co-morbidities and outcomes were identified and recommendations for additional radiological examinations were made. A second study investigated treatment of pelvic injury. Circumferential pelvic binders are used to control bleeding in such cases; they allow rapid closure of the pelvic ring and are particularly valuable in pre-hospital care. The research demonstrated that clinical outcome depends strongly on the positioning of the binders: radiographic examination showed that placement at the level of the greater trochanters leads to a significant reduction in the rate of pubic bone separation [5]. (This research won 1st prize at the Combined Services Orthopaedic Society 2011 meeting.)

Peer-reviewed funding totalling >£5M has been obtained from the Royal British Legion, Dstl and others to establish CBIS and run research in it [6].

### 3. References to the research (indicative maximum of six references)

\* References that best indicate quality of underpinning research.

\*[1] Masouros SD, Newell N, Bonner TJ, Ramasamy A, West ATH, Hill AM, Clasper JC, Bull AMJ. Design of a traumatic injury simulator for assessing lower limb response to high loading rates. *Ann Biomed Eng.* 2013;41:1957-1967. DOI: 10.1007/s10439-013-0814-6.

\*[2] Ramasamy A, Hill AM, Masouros S, Gibb I, Bull AMJ, Clasper JC. Blast-related fracture patterns: a forensic biomechanical approach. *J. R. Soc. Interface* 2011;8:689–698. DOI: 10.1098/rsif.2010.0476..

[3] Ramasamy A, Hill AM, Masouros SD, Gordon F, Clasper JC, Bull AMJ. Evaluating the effect of vehicle modification in reducing injuries from landmine blasts. An analysis of 2212 incidents and its application for humanitarian purposes. *Accident Analysis & Prevention.* 2011;43:1878-1886. DOI: 10.1016/j.aap.2011.04.030.

\*[4] Ramasamy A, Hill AM, Phillip R, Gibb I, Bull AMJ, Clasper JC. The Modern “Deck-Slap” Injury—Calcaneal Blast Fractures From Vehicle Explosions, *J Trauma Injury, Infection & Critical Care* 2011; 71: 1694-1698. DOI: 10.1097/TA.0b013e318227a999.

\*[5] Bonner TJ, Eardley WGP, Newell N, Masouros S, Matthews JJ, Gibb I, Clasper JC. Accurate placement of a pelvic binder improves reduction of unstable fractures of the pelvic ring, *J. Bone & Joint Surgery* 2011; 93B: 1524-1528. DOI: 10.1302/0301-620X.93B11.27023.

[6] Exemplar grants to AMJ Bull: “Centre for Blast Injury Studies,” The Royal British Legion, £5,000,000. 1-11.2011 – 30.10.2016; “Unravelling nerve dysfunction after bomb blast,” Dstl, £261,998, 1-10-2011 – 31-3-2012; “Blast Fellowship,” ABF The Soldiers’ Charity, 1-6-2011 - 31-5-2014, £119,500

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**4. Details of the impact** (indicative maximum 750 words)

The research of CBIS has improved the design, testing and operation of military vehicles, and informed the purchasing of combat boots. It has also altered military clinical practice and surgical training of troops. Finally, it has provided data and physical and computational models used in the commercial development of military crash test dummies. NOTE: the MoD has severely restricted the details that we can reveal. We give names of five people (the maximum permitted) who are able to confirm verbally the most important parts of the impact; names of people prepared to confirm other aspects are available on request.

Impact on vehicles and equipment

Systematic primary prevention - in the form of posture and placement of personnel, and vehicle and clothing design - is key to reducing injury.

**Posture and Placement.** Substantial impact has arisen from the CBIS findings concerning effects of posture and position within a vehicle on the pattern and severity of injury. For obvious security reasons, details of this information cannot be released even under confidentiality agreements. We are permitted to state that the results have been the subject of two formal MoD briefings and a confidential Dstl report (DSTL/TR48994, "The effect of seating position on lower limb injuries in under-vehicle explosions," August 2010) that relates posture to injury severity and vehicle design. Dr Alan Hepper of Dstl is prepared to confirm the impact [A].

**Vehicle design and testing.** Impact has also arisen from CBIS research into engineering design and material selection for vehicles, their equipment, and surrogates for testing. The injury mitigation efficacy of various floor mat designs was the subject of Dstl consultancies by CBIS staff from Feb 2013, managed through ICON (Imperial Consultants). We are not permitted to disclose the full results but impact can be confirmed by Mr Ian Elgy at Porton Down [B]. CBIS research on vehicles and injury data has informed the policy of the NATO Human Factors and Medicine task group 198 concerning STANAG 4569, the NATO standardisation agreement that defines the system qualification and acceptance procedures used in determining the protection level for logistic and light armoured vehicles from kinetic energy and artillery threats [C]. CBIS research on the appropriate use of posture and type of surrogates resulted in a change in the interpretation of live blast tests when determining the protection afforded by vehicles against IED strikes.

**Footwear design.** The CBIS studies concerning efficacy of two commonly used combat boots in mitigating calcaneal fractures resulted in reports with recommendations being sent to MoD procurement, who provided materials and advice for the research. We cannot reveal the use of this information by the MoD; however, some of the data were published in the open literature [D].

Impact on surgical and clinical practice

Clinical data analysis and modelling from CBIS have had direct impact on surgical practice.

One specific instance of impact derives from the research on the severity of calcaneal fractures described above. A direct result of the finding that these fractures are associated with a poor outcome is that, since 2012, limbs have been amputated earlier than hitherto. This means that the casualty is not subjected to unnecessary repeat operations and severe pain, and then still has to have the amputation. A second consequence of the research has been to change the surgical management of these fractures to more minimally invasive techniques in order to reduce osteomyelitis (bone infection) and its long-term effects. We are not permitted to give the number of procedures but the Consultant Trauma Surgeon, Royal Centre for Defence Medicine [E], is able to

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confirm the impact of CBIS research verbally. Also, the Armed Forces Compensation Scheme Medical Board has, with direct input from our work, recently upgraded the compensation for calcaneal fractures in line with below knee amputations.

A second specific instance derives from the CBIS study of unstable pelvic fractures, also described above. Such injuries are a frequent consequence of explosion, and are potentially life-threatening: mortality is around 10% and internal bleeding is the major contributor to this. The research showing that placement of pelvic binders at the level of the greater trochanters reduces pubic bone separation has changed clinical practice in Afghanistan and at major trauma centres in UK since 2012. Again, we are not permitted to give the number of procedures but the Defence Professor of Surgery [F] is able to confirm the impact of CBIS research verbally.

The pelvic binder technique identified by CBIS is now included as part of Military Operational Surgical Training (MOST), a compulsory course for troops being deployed; CBIS staff participate in the teaching.

**Commercial Impact**

CBIS research data, communicated through an ICON consultancy, are being used in the design of crash test dummies by Humanetics Innovative Solutions Inc, who have been contracted under a US\$80M Department of Defence programme to deliver a new anthropomorphic test device specifically for testing underbody blast by 2018. Humanetics (like Dstl) use the physical and computational models developed by CBIS.

**5. Sources to corroborate the impact** (indicative maximum of 10 references.)

[A] Dstl Fellow, Biomedical Sciences, Porton Down, will confirm the impact of CBIS findings concerning effects of posture and position within a vehicle.

[B] Capability Lead - Blast & IED Protection, Dstl Physical Protection Group, Porton Down, will confirm the impact of CBIS research on floor mat design.

[C] Chairperson of NATO HFM-198, will confirm the influence of CBIS research on policy concerning STANAG 4569.

[D] Newell N, Masouros SD, Pullen AD, Bull AMJ. The comparative behaviour of two combat boots under impact. *Injury Prevention*. 2012; 18: 109-112. DOI: 10.1136/ip.2010.031344, Describes the non-confidential part of CBIS research into blast-mitigating effects of combat boots, used by MoD procurement in conjunction with confidential information.

[E] Consultant Trauma Surgeon, Royal Centre for Defence Medicine will confirm the impact of CBIS research on changing surgical practice related to the management of calcaneal fractures from blast.

[F] Defence Professor of Surgery, Queen Elizabeth Hospital Birmingham, will confirm the impact of CBIS research on pelvic binder procedures.