

Institution: Imperial College London		
Unit of Assessment: 12 Engineering		
Title of case study: Mitigation, Treatment and Influence within the Field of Blast Injuries		
Period when the underpinning research was undertaken: 2008 - 2020		
Details of staff conducting the underpinning research from the submitting unit		
Name(s): Prof Anthony Bull Dr Spyros Masouros Dr Angela Kedgley Prof Jon Clasper Dr Arul Ramasamy	Role(s) (e.g. job title): CBIS Director, Professor of Musculoskeletal Mechanics CBIS Associate Director, Reader in Injury Biomechanics CBIS Academic, Senior Lecturer CBIS Clinical Lead, Visiting Professor CBIS Academic, Honorary Clinical Senior Lecturer	Period(s) employed: Mar. 2000 – present Dec. 2012 – present Jan. 2011 – present Nov. 2010 – present Mar. 2013 - present
Period when the claimed impact occurred: 1 Aug 2013 – 31 Dec 2020		
Is this case study continued from a case study submitted in 2014? Yes		
<p>1. Summary of the impact</p> <p>The Centre for Blast Injury Studies (CBIS) focuses on the mitigation, treatment and rehabilitation of blast injuries. CBIS employs a truly interdisciplinary approach, combining engineering, scientific and clinical methodologies and expertise. Whilst the research focuses on injuries within military populations, the knowledge is also highly relevant in the growing number of civilian blast incidents. The impact of our research during the current REF period is:</p> <p><u>IMPROVED MITIGATION</u></p> <p>11) Influenced the purchasing decision for <u>108,500 pairs</u> of new Army gloves.</p> <p>12) Contributed to a NATO report on the assessment methods and the criteria for armoured vehicle qualification against explosive threats. This has direct influence on <u>occupant safety</u> of armoured vehicles, an industry worth <u>multiple billions</u> of pounds.</p> <p><u>ADVANCED TREATMENT OF BLAST INJURIES</u></p> <p>13) Confirmed the correct application of pelvic binders which continues to be standard method for UK military personnel training. During 2019/20, <u>1,352 UK military personnel</u> were trained in the correct application of the binder.</p> <p>14) Co-led the production and distribution of the Paediatric Blast Injury Field Manual. <u>2,300 paper copies</u> of the manual have been distributed to NGOs and the digital versions, available in <u>5 languages</u>, have been <u>downloaded 763 times</u>.</p> <p><u>INFLUENCED POLICY AND PRACTICE</u></p> <p>15) Continually informed the Armed Forces Compensation Scheme tariffs for lower limb injury, which is relevant to the ongoing treatment and care of <u>1,121 service personnel</u> who sustained lower limb injuries in Afghanistan (2006-14).</p> <p>16) Provided <u>expert testimony</u> for judiciary decision making at the Inquest into the <u>21 killed</u> in the Birmingham Pub Bombings, such that judicial decisions were made based on scientific evidence. CBIS is currently providing expert testimony for the Inquiry into the <u>22 killed</u> in the Manchester Arena Bombing.</p>		
<p>2. Underpinning research</p> <p>The Centre for Blast Injury Studies (CBIS) is housed within the Department of Bioengineering and is led by Bull, Clasper, Masouros (Bioengineering), McGregor (Surgery & Cancer) and Sharp (Brain Sciences). CBIS was established in 2011, expanding on the cross-departmental Blast Research Group from 2008-11. CBIS received its second 5-year block of funding in 2016, allowing the team to build on previous work and expand its remit. The unique aspect of CBIS is the collaboration between engineers, scientists and clinicians in researching blast</p>		

injuries. The Centre employs a clinically-led approach to mitigation, treatment and rehabilitation of blast injuries.

Historically, much of CBIS' work has focused on the effects of improvised explosive devices (IEDs) as these represented a significant threat to Service Personnel serving in Iraq and Afghanistan. However, in recent years, CBIS' work has also been translated to civilian blast injuries (highlighted below in I4 and I6). Blast events accounted for the deaths of 347 UK Service Personnel in Iraq (2003-11) and Afghanistan (2001-14), and injuries to many more. There are also tens of thousands of civilian injuries and deaths globally as a result of blasts in conflict, terrorist incidents, and accidents. Those that survive endure life-changing injuries. The Centre's impact is underpinned by the following research by Bull, Clasper, Masouros, Kedgley and Ramasamy, which **integrates engineering and clinical knowledge**:

- 1) **Mitigation [R1- R3, I1- I2]:** Much of CBIS's work seeks to improve the design of armoured vehicles and personal protective equipment, which prevents or reduces the effects of blast events on Service Personnel. CBIS uses combinations of clinical data, and computational and physical models to analyse the mechanism of blast injuries. CBIS has quantified the injury tolerance of the metacarpophalangeal and proximal interphalangeal joints in the hand when exposed to different impacts; this is important because injuries to these joints are particularly disabling [R1]. We have demonstrated that the mechanism of injury for those seated in a military vehicle during an under-vehicle explosion depends on posture [R2], and have quantified the risk of penetrating injury to the tibia as a result of fragments energised by blast [R3]. Research in R1-R3 provides routes to mitigation strategies.
- 2) **Treatment [R4 - R5, I3 - I4]:** CBIS also has a focus on the treatment of blast injuries. One aspect of this is understanding pelvic blast injury. Pelvic binders are used by emergency teams (civilian and military); they are essentially belts designed to compress the pelvis together when it is fractured, with the objective to stop haemorrhage. CBIS' work has shown that placing the pelvic binder above the level of the greater trochanters is an inadequate method of reducing pelvic fractures [R4] and may delay the cardiovascular recovery of the patient. A second aspect of the treatment work at CBIS is the co-leadership of the Paediatric Blast Injury Partnership and the development of the Paediatric Blast Injury Field Manual. The research has discussed the injury patterns seen in children who are victims of blast injuries, has shown that some injury characteristics in children are distinct from adults, and that further knowledge of the diverse patterns of injury will be required to optimise the care provided to children after a blast event [R5].
- 3) **Rehabilitation [R6 - R7, I5 - I6]:** CBIS identified first, in the early years of the recent Afghanistan conflict, the re-emergence of the 'deck-slap' foot; a severe injury to the foot and ankle due to the rapid rise of the vehicle's floor when attacked by a mine. CBIS showed that these severe injuries are associated with very poor outcomes [R6]. Direct Skeletal Fixation (DSF) for bilateral lower limb, above knee amputees, is also a focus. Study results showed the improvements experienced by the initial DSF cohort and its use as an option for those where socket prostheses are difficult [R7].

3. References to the research

- R1:** Carpanen D, **Kedgley AE**, Shah DS, Edwards DS, Plant DJ, **Masouros SD** (2019). Injury risk of interphalangeal and metacarpophalangeal joints under impact loading. *Journal of the mechanical behaviour of biomedical materials*, 97: 306-311. (<https://doi.org/10.1016/j.jmbbm.2019.05.037>).
- R2:** Grigoriadis G, Carpanen D, Webster CE, **Ramasamy A**, Newell N, **Masouros SD** (2018). Lower limb posture affects the mechanism of injury in under-body blast. *Annals of Biomedical Engineering*, 47(1): 306-16. (<https://doi.org/10.1007/s10439-018-02138-4>).
- R3:** Nguyen T-T N, Carpanen D, Stinner D, Rankin I, **Ramasamy A**, Breeze J, Proud WG, **Clasper JC**, **Masouros SD** (2020). The Risk of Fracture to the Tibia from a Fragment Simulating Projectile. *Journal of the Mechanical Behavior of Biomedical Materials*, 102: 103525. (<https://doi.org/10.1016/j.jmbbm.2019.103525>)
- R4:** Bonner TJ, Eardley WG, Newell N, **Masouros S**, Matthews JJ, Gibb I, **Clasper JC** (2011). Accurate placement of a pelvic binder improves reduction of unstable fractures of the

pelvic ring. *Journal of Bone and Joint Surgery*, 93(11): 1524-1528. (<https://doi.org/10.1302/0301-620X.93B11.27023>).

R5: Millwood Hargrave J, Pearce P, Mayhew ER, **Bull A**, Taylor S (2019). Blast injuries in children: a mixed-methods narrative review. *BMJ Paediatrics Open*, 3(1). (<http://dx.doi.org/10.1136/bmjpo-2019-000452>).

R6: **Ramasamy A**, Hill AM, Phillip R, Gibb I, **Bull AMJ**, **Clasper JC** (2011). The modern “deck-slap” injury - calcaneal blast fractures from vehicle explosions. *The Journal of Trauma: Injury, Infection & Critical Care*, 71(6): 1694-1698.(DOI: [10.1097/TA.0b013e318227a999](https://doi.org/10.1097/TA.0b013e318227a999)).

R7: McMenemy L, **Ramasamy A**, Sherman K, Mistlin A, Phillip R, Evriviades D, Kendrew J (2020). Direct Skeletal Fixation in bilateral above knee amputees following blast: 2 year follow up results from the initial cohort of UK service personnel. *Injury*, 51(3): 735-743. <https://doi.org/10.1016/j.injury.2020.01.006>

4. Details of the impact

IMPACT RELATING TO MITIGATION

I1) Influenced the purchasing decision for new military gloves, [R1, E1]: As a result of work in R1, Dr Masouros was invited to contribute to the Ministry of Defence’s (MoD) project FULMAR in 09.2018, the deliverable of which was a tender for the new UK Army glove. The glove has been procured to all Army personnel (currently 108,500 pairs). Dr Masouros was the only non-MoD member on the project. CBIS’s work was specifically acknowledged within the technical specification that accompanies the tender [E1]. In [E1], Senior Programme Manager within Defence Equipment & Support notes:

“Dr Masouros was invited as an expert on injury biomechanics, due to his and his colleagues’ work at Imperial on quantifying the risk of injury to the hand due to blunt impact and on assessing dexterity and protective ability of existing gloves. His contribution to the working group was substantial, and proposals that he made were taken into account when developing the tender.”

I2) Influenced armoured vehicle design, [R2, E2]: Research in R2 demonstrated the impact of posture on mechanism of injury for those military-vehicle occupants during an under-vehicle explosion, information which is not captured by current injury criteria used in vehicle assessment by national authorities and test houses. Dr Masouros’ membership of the NATO Human Factors and Medicine (HFM) Research Task Group (RTG) 271 from 2016-20 resulted in substantial contribution to the recommendations made to NATO’s standardisation committee (STANAG 4569) through the group’s NATO report specifically on accounting for different postures. By directly influencing the recommendations for the NATO standard on injury assessment criteria of armoured vehicles (an industry which is worth billions of pounds), CBIS’ work impacts the safety of occupants in armoured vehicles. Chair of NATO RTG 271 and US’s Department of Defence writes in [E2]:

“I invited Spyros to join the group as a non-government expert on blast-injury biomechanics.... His research and expertise...has been influential in the group’s understanding of the current state-of-the-art on injury modelling, especially on the lower extremity. ...our report suggests a change in the injury threshold for the lower leg and offers new insights in the appreciation of the injury risk depending on posture.”

IMPACT RELATING TO TREATMENT

I3) Recommended changes to the application of pelvic binders following blast injury, [R4, E3]: The research published within R4 demonstrated the benefits of accurate positioning of the pelvic binder, and continues to be standard method within UK military training. In E3, Colonel Stephen Harmer of the Defence Medical Academy confirms that in the year 2019/20, 1,352 military personnel were trained in the correct placement, with similar numbers trained each year during this REF period:

- *“Battlefield Advanced Trauma Life Support – 869*
- *Immediate Emergency Care Provider (RAF) – 97*

- *Remote Team Medic – 8 (enhanced training for non-medical personnel (new course so numbers will increase by at least x10))*
- *Medic Phase 2 trade training – 314*
- *sS RAF Medic – 44*
- *Post Basic Professional Qualification Course (RN) – 20*
- *Total = 1352”*

The military are not able to specify the number of lives saved through correct application of the pelvic binder in the military population, but with more than 1,000 military personnel per year being certified in the correct use of the binder, those who might be exposed to blast, or other traumatic injuries where use of the pelvic binder is required, have a much higher chance of survival as a direct consequence of our research.

- 14) Contributed to the production and distribution of the Paediatric Blast Injury Field Manual, [R5, E4]:** The Centre has played a leadership role in the formation and development of the Paediatric Blast Injury Partnership (from 2017). This partnership, which includes Save the Children and academics and clinicians from other Universities and Healthcare Trusts, has resulted in a field manual [E4] being produced and distributed in English, Arabic, Dari, Pashtun and French within three years of the initial scoping meeting. The impact of the manual to date is its far-reaching distribution and uptake: 1,800 English copies have been distributed to small/medium medical NGOs in Sierra Leone, Yemen, Iraq, Syria, Turkey, The Philippines, Afghanistan, Nigeria and Myanmar; 500 Arabic copies have been circulated in Syria and Yemen; 763 users have downloaded the digital manuals; it has also been circulated to 700 medics throughout the US Combat Casualty Care and Joint Trauma System; and it is currently being used to train medics and first responders from humanitarian organisations. The World Health Organisation (WHO) has circulated copies of the Arabic PDF version and the International Federation of the Red Cross are using the Field Manual for all their paediatric blast first aid training across the world. The manual is being used to save the lives of children around the world where children are exposed to the threat of conflict or post-conflict blast.

INFLUENCING POLICY AND PRACTICE

- 15) Continued to inform changes to the Armed Forces Compensation Scheme (AFCS) about lower limb injuries to influence changes to pension benefits, [R6-R7, E5]:** The Centre’s research on lower limb injuries [R6-R7] continues to be used by the AFCS Medical Board to inform the compensation scheme for military personnel who have suffered injuries relevant to military service. CBIS’ research informs fairer decision making for the injured. The Chief of Defence Personnel Medical Advisor at the Ministry of Defence, explains in [E5] that *“Lower extremity trauma during Afghanistan 1 April 2006 until 30 Nov 2014 resulted in 2804 injuries to 1121 personnel... Many of these injuries ... were previously non-survivable so Blast Centre research ... has been key in informing tariff values, clinical management and rehabilitation...”*. Whilst many awards were made during the conflicts, a number of personnel have requested a review of their awards since. Between 2013/14 and 31 March 2020 (this REF period) there have been *“about 100 lower limb revised awards... The compensation available to these individuals has therefore been directly influenced by the Blast Centre’s research. ... It also continues to inform compensation policy as new research emerges.”*
- 16) Informed judiciary decision making, [R1-7, E6-E7]:** The research within R1-R7 exemplifies the expertise of Centre members in the analysis of mechanisms of injury after blast events. The Centre therefore provides expert testimony such that judicial decisions are based on scientific facts. In [E6], the Solicitor to the Inquests into the 1974 Birmingham Pub Bombings writes:
- “I approached Professor Anthony Bull in March 2017 to ask him to form a panel of experts for the...Inquests. ... The panel’s expertise in the science of blast events and the clinical management and outcomes of blast injuries was of great importance in the Inquests and to understand how each person died and whether their injuries were survivable.”*

In E7, the Coroner writes:

“They brought clarity and simplicity to complex issues and, I am sure, occasioned great benefit for the jury in understanding the nature and consequences of the explosions. This was an important (if distressing) aspect of the inquests and was of considerable assistance in helping to explain the statutory question of how the 21 came by their deaths”.

Further to Professors Bull and Clasper providing written and oral evidence, the panel also provided recommendations to the Coroner about lessons learned for the prevention of future deaths. The panel is currently involved in the analysis of the impact of the improvised explosive device on each of the 21 people who were killed in the 2017 terror attack.

5. Sources to corroborate the impact

- E1:** Letter from **DE&S** confirming Masouros' involvement in project FULMAR, to define the tender for new Army gloves.
- E2:** Letter from **NATO HFM RTG** Chair confirming Dr Masouros' involvement in the RTG report to STANAG who publishes standards.
- E3:** Email from Defence Medical Academy, Defence Medical Services confirming numbers trained in correct pelvic binder placement.
- E4:** Paediatric Blast Injury Field Manual, downloadable version: https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/centre-for-blast-injury-studies/PBIP-BlastInjuryManual2019_I_web.pdf [accessed 10 October 2019]. Link archived [here](#).
- E5:** Letter from MoD Chief of Defence Personnel Medical Adviser, confirming CBIS' input to compensation scheme tariffs and numbers who have benefitted from review of their compensation award since 2013/2014.
- E6:** Letter from Solicitor to Inquest for the 1974 Birmingham Pub Bombings and the Inquiry into the 2017 Manchester Arena Bombing, confirming the panel's role in the Inquest and Inquiry.
- E7:** Letter from Coroner for the Birmingham Inquests (1974), confirming the panel's role in the Inquest.