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THE ROYAL BRITISH LEGION

THE ROYAL BRITISH LEGION
CENTRE FOR BLAST INJURY STUDIES
AT IMPERIAL COLLEGE LONDON

2022

CBIS Annual Report and 10-year Review

The Royal British Legion
Centre for Blast Injury Studies
at Imperial College London

January 2024

Imperial College London

Centre for Blast Injury Studies
Annual Report

The Royal British Legion Centre for Blast Injury Studies
at Imperial College London
www.imperial.ac.uk/blast-injury

London, January 2024

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Introduction from Centre Director

2022 was a fantastic year for the Centre for Blast Injury Studies. Although the major effects of COVID-19 persisted, we were able to make headway and continue to deliver on our translational research vision. This year marked 10 years of continuous funding from the Royal British Legion for which we are grateful. The Legion's support has enabled us to develop world-leading expertise, capabilities that are unique, research outputs that are groundbreaking, and translation for the benefit of armed forces personnel, veterans, and many others affected by conflict injuries.

This last year was also transitional in many ways. Centre members recognised that there are many other areas where our knowledge and capabilities can be applied and so the Centre has been moving towards using its expertise in broader areas of translational injury studies research. We have established a *Centre for Injury Studies* with CBIS a key pillar.

One of the major items of societal impact where the Centre played a leading role was the Manchester Arena Inquiry. We chaired and participated in the Expert Panel that provided input to the Chairman of the Inquiry on cause of death and likelihood of survival of the 22 people who died following the attack on the Manchester Arena on the 22nd May 2017. The Inquiry's report on the Centre's work in this area came out in November 2022 and was the culmination of many years of work that provided clarity and assistance to the Inquiry.

On a personal note, I would like to publicly acknowledge the support that Lord Boyce provided to the Centre as well as his encouragement to me as the Director. I miss our Friday afternoon conversations where he gently, firmly, and graciously held me to account and provided ideas and strategic input.

Professor Anthony M J Bull FREng
Director, The Royal British Legion Centre for Blast Injury Studies at Imperial College London

Admiral of the Fleet the Lord Boyce KG GCB OBE

Admiral of the Fleet the Lord Boyce worked tirelessly for the Centre for Blast Injury Studies. He was the inaugural chair of the Advisory Board and was instrumental in so many key initiatives in the Centre: our co-leadership in establishing the ADVANCE study, securing the second 5 years of funding from the Royal British Legion to continue the work that is outlined in this report, and strengthening our links with our stakeholders in defence. We were saddened to hear of his passing in 2022 and would like to dedicate this report to his memory and all the work that he did to make this all possible.

Lord Boyce dedicated 42 years to the Royal Navy from joining in 1961 to retiring as Chief of Defence Staff and professional head of the Armed Forces in 2003. He served on seven submarines during his early career, rising from the rank of submariner to command HMS Brilliant and gain the appointment as Captain (SM) Submarine Sea Training in addition to a short time at the Ministry of Defence. He moved back to the Ministry of Defence and the Directorate of Navy Plans and Programmes as Assistant Director (Warfare) in 1986 and continued to move through the ranks becoming Vice Admiral in 1994. In 1998 he was appointed First Sea Lord and Chief of Naval Staff, and First and Principle Naval ADC, serving as the professional head of the Royal Navy until January 2001. He was then awarded the honorary appointment of Admiral of the Fleet in 2014.

Lord Boyce received several honours throughout his service. He received his OBE in 1982 and in 1995 he was knighted in the New Year Honours List and appointed GCB in June 1999 (GCB is the Knight Grand Cross which is a class of the Most Honourable Order of the Bath). It was in June 2003 that Lord Boyce was elevated to the peerage. He was appointed as the King of Arms of the Order of the Bath from 2009-2018 and was made a Knight Companion of the Order of the Garter (KG) in April 2011.

In addition to acting as the Chairman of the Advisory Board of CBIS, he was also very active in other pro-bono/charity activities. As Chairman of our Advisory Board, he was key in bringing our issues to the House of Lords and was an enthusiastic advocate of the work that we were doing. He was also Head of the Board of Trustees for the ADVANCE Charity.

We remember Lord Boyce with fondness and in gratitude for his lifetime of service.

Celebrating 10 years of The Royal British Legion Centre for Blast Injury Studies

2008
- Imperial Blast is established

2012
- The Royal British Legion (TRBL) funds the Centre for Blast Injury Studies (CBIS)
- Advisory Board is established (Chaired by Admiral of the Fleet the Lord Boyce KG GCB OBE)

2013
- HRH Prince Harry opened the Centre's newly refurbished laboratories in South Kensington
- Blast Injury Rehabilitation added as a scientific theme in collaboration with Defence Medical Rehabilitation Centre at Headley Court

2015
- TRBL funding is renewed for another 6 years
- First PhD awarded to student directly and solely funded by the Centre
- Blast Injury Science and Engineering book (edition 1) is published

2016
- ADVANCE (Armed Services Trauma Rehabilitation Outcome Study) is started in collaboration with Headley Court and King's College London.
- LIVEX - Defence Medical Services training exercise

2018
- 10 years of Imperial Blast
- Paediatric Blast Injury Partnership is formed
- Military Amputee Research Advisory Group is established
- 1st Blast Injury Conference

2019
- 2nd Blast Injury Conference
- Paediatric Blast Injury Field Manual launched

2020
- Imperial College tops the Research Excellent Framework (REF) assessment with case study from CBIS

2021
- 3rd Blast Injury Conference (online)

2022
- 10 years of CBIS celebration
- 2nd edition of Blast Injury Science and Engineering book published

Governance

In 2012, the Royal British Legion Centre for Blast Injury Studies at Imperial College London (CBIS), was established as an evolution from Imperial Blast. The financial support from the Royal British Legion enabled the formalisation of the management structure, strategy, and governance, which has grown and adapted as the Centre has matured.

The Royal British Legion

The Royal British Legion have been the core funders of the Centre and provided ongoing oversight to the Centre's work. Members of The Royal British Legion have attended events run by the Centre and Professor Bull met with the Legion's Director of Operations for discussions about the Centre and formal reporting on a regular basis. We will miss our formal interactions with The Royal British Legion but will continue to communicate our outputs and work with the organisation as our aims remain closely aligned.

Imperial College London

Imperial recognised CBIS as one of twenty Centres of Excellence. The Centre therefore provided an annual formal report to the Vice Provost of Research and Enterprise and smaller updates about activities every two months. The formal reports were considered and scored on the risk to sustainability, the Centre's original objectives, its outputs, and the leadership and governance. The institution's continued support of the Centre was contingent upon good scores in these categories. The College's recognition of the Centre's excellence gave CBIS a high-profile institutional backing.

Management Group

During the last 10 years of CBIS, the Management Group have met regularly to discuss the strategic direction and operational workings of the Centre. This consisted of the Centre Director (Professor Anthony Bull), Clinical Lead (Professor Jon Clasper), two Associate Directors (Professor Alison McGregor and Dr Spyros Masouros) and the Research Programmes Manager(s) (Dr Lucy Foss and Dr Emily Lumley). They were joined by another Associate Director in 2019, Professor David Sharp from the Department of Brain Sciences.

Advisory Board

The CBIS Advisory Board have met twice a year throughout the Centre's lifetime and provided advice to the Centre's Management Group. Throughout this time, it was chaired by former Chief of the Defence Staff, Admiral of the Fleet the Lord Michael Boyce KG GCB OBE. Lord Boyce was a dedicated and enthusiastic chair of the Advisory Board which functioned to provide independent and external advice, strategic oversight and monitoring, and an ambassadorial purpose for the Centre. Therefore, we were all greatly saddened when, in November 2022, he passed away after battling cancer for a long period. His personal struggles and illness never diminished his enthusiasm for the role or the Centre, and we are incredibly grateful for his commitment.

Along with Lord Boyce, other members of the Advisory Board are listed below (with the years they served on the board):

- Zoltan Bozoky, UK Department of Health; Chief Strategy Officer responsible for research which informs health care in England. (2012 – 2015)
- Ian Stopps CBE, Chairman of Raytheon UK (2012 – 2019) – sadly he passed away in October 2019
- Sir Keith O'Nions FRS Hon.FREng, Former Chief Scientific Advisor, Ministry of Defence (2016 – 2020)
- Professor Keith Willett CBE, National Clinical Director for Trauma Care, Department of Health (2016 – 2021)
- Lt Gen Louis Lillywhite CB, MBE, QHS, Retired Surgeon General (2016 – 2021)
- Kate Davies OBE, Director of Commissioning for NHS England: Armed Forces & their Families (2016 – 2022)
- Richard Swarbrick, Head of Armed Forces Health Partnerships and Engagement at NHS England (2018 - present)
- General Sir Tim Granville Chapman GBE KCB, former Vice Chief of the Defence Staff & Programme Director Defence and National Rehabilitation Centre (2012 – present)
- David Henson MBE, veterans' representative (2012 – present)
- Professor Sir Anthony Newman Taylor CBE, Chairman of the Independent Medical Expert Group of the Armed Forces Compensation Scheme (2012 – present)
- Sir Bill Rollo, former Deputy Chief of Defence Staff (Personnel & Training), Commonwealth War Graves Commission, King Edward VII Hospital, and the Scar Free Foundation (2019 – present)
- Major General Tim Hodgetts CB CBE KHS OStJ DL, Surgeon General (2021 – present).

Military Amputee Research Advisory Group

The Military Amputee Research Advisory Group met for the first time in September 2018 as a way of involving patient experts in CBIS and gaining their perspective in the work that is conducted. The Group is chaired by Professor Alison McGregor and the meetings have included very useful discussions about rehabilitation and prosthetics. The Advisory Group have met annually and provided input into projects that work with military amputees and given advice about protocols and delivery. The Group's membership includes military amputees, military clinicians, and representatives from veterans' organisations. The meeting in 2022, was focused on the future of the group in the light of moving from CBIS to the overarching Centre for Injury Studies. All members were keen to continue the Group in some form and interested in the possibility of expanding it to include more civilian amputee issues.

Staffing

The Centre has grown and evolved over the last 10 years to average around 50 members at its largest, from seven different departments within the College: Bioengineering, Brain Sciences, Civil & Environmental Engineering, Dyson School of Design Engineering, National Heart & Lung Institute, Physics, and Surgery & Cancer. Our researchers work at the interface of several different disciplines.

As part of this there have been 16 core academics within the Centre, working across different clinical priorities and supervising PhD students and postdoctoral researchers.

- Professor Anthony Bull (Bioengineering) – Centre Director
- Professor Jon Clasper (Bioengineering) – Clinical Lead
- Dr Spyros Masouros (Bioengineering) – Associate Centre Director
- Professor Alison McGregor (Surgery & Cancer) – Associate Centre Director
- Professor David Sharp (Brain Sciences) – Associate Centre Director
- Dr Robert Dickinson (Surgery & Cancer)
- Dr Mazdak Ghajari (Dyson School of Design Engineering)
- Dr Claire Higgins (Bioengineering)
- Dr Angela Kedgley (Bioengineering)
- Dr Andrei Kozlov (Bioengineering)
- Dr Andrew Phillips (Civil and Environmental Engineering)
- Dr Bill Proud (Physics)
- Professor Sara Rankin (National Heart & Lung Institute)
- Dr Tobias Reichenbach (Bioengineering)
- Professor Andrew Rice (Surgery & Cancer)
- Professor Mark Wilson (Surgery & Cancer)

CBIS news from 2022

PhDs awarded

We would like to congratulate the following people who successfully defended their PhD theses in 2022! This marks the penultimate year of graduations from CBIS-funded PhD students.

Alastair Darwood – Translation Approaches for the Enhancement of Osteogenesis in Mesenchymal Stem Cells.

Diana Toderita – The biomechanical effect of prosthetic design for transfemoral amputees.

Sarah Dixon-Smith – "An interval of comfort": postamputation pain & long-term consequences of amputation in British First World War veterans, 1914-1985.

Leavers

We bade a very fond farewell to a few Centre members in 2022. We wish them all the best in their new roles and look forward to continuing to collaborate with them in the future.

Dr Alistair Darwood – Working for his own company.

Brieuc Panhalleux – Working in a local start-up company.

Dr Pouya Amiri – Assistant Professor in Canada.

Achievements

Each year we like to celebrate the achievements of Centre members. We would like to congratulate Professor Alison McGregor who is now a Fellow of the Royal College of Physicians. Congratulations also to Dr Spyros Masouros who won a CSA (Chief Scientific Advisor) Special Commendation for "Optimising Protection and Treatment after Blast Injury".

Facilities

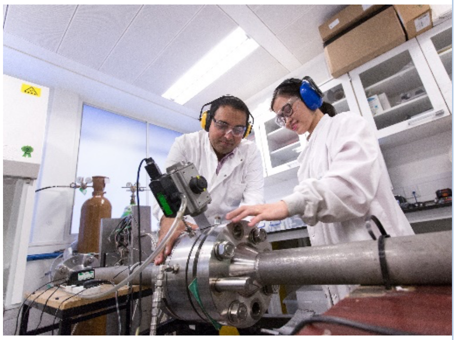
The facilities available at the Centre are world-class and enable our researchers to accurately model blast injuries and the effects of blast in various ways. Many of these have been specifically designed to model blast injuries and are unique to CBIS.

AnUBIS (Anti-vehicle Underbelly Blast Injury Simulator)

AnUBIS is a pneumatically driven device able to accelerate a 42kg plate up to velocities seen in the floor of vehicles targeted by mines. Combining multiple-sensor data, high speed video, and medical imaging, the mechanism and severity of the injury sustained by the lower limb can be quantified. This is used to inform and validate computational models, assess the effect of leg positioning on injury severity, assess surrogate biofidelity, and assess the effectiveness of full-scale mitigation technologies in reducing injury severity.

Shock Tube

The shock tube allows CBIS researchers to generate a well-defined pressure output of varying intensity and duration as a surrogate for blast waves in the laboratory. Blast waves are responsible for a range of injuries including pulmonary, nerve, musculoskeletal and brain injuries. The shock tube at CBIS was designed and built to subject tissue (cellular and organ) to controlled pressure pulses that simulate primary blast exposure in the battlefield. Air pressure is increased behind one or more diaphragms, and when increased enough, eventually the diaphragms will fail. This sudden rupture releases the pressure into the low-pressure section, creating a pressure wave.



Split Hopkinson Pressure Bar (SHPB)

The split-Hopkinson pressure bar (SHPB) is a conventional loading device that has been successfully modified by CBIS for studying the effects of blast loading on biological tissues and engineering components. An SHPB system generally consists of three long cylindrical bars termed projectile, input bar, and output bar. Different pulses can be achieved depending on the arrangement, the geometrical and material properties of the bars, the different modes of loading (compression, tension, or torsion) and the loading conditions. An SHPB system typically exposes samples to loads of strain rates in the range of 10^3 – 10^4 s^{-1} and with tuneable time durations between hundreds of microseconds to tens of milliseconds.

Drop Tower

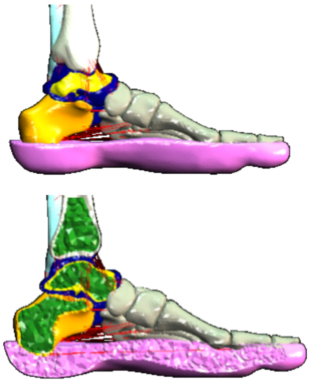
The drop tower is used to reconstruct injury mechanisms that are seen in the battlefield, such as compression fractures of the spine. In addition, CBIS uses drop weight loading for impact testing. We use this technique to characterise the behaviour under impact of structures such as bone, ligament, and the human heel fat pad, but also shock absorbing materials such as those used in combat boots.

Gas Gun

The gas gun is used to produce shock waves in biological materials. The types of pressure and durations seen in this system reflect the first, high-intensity levels seen in the blast process. This testing facility allows us to produce microsecond (one-millionth of a second) duration loading and recover the sample for close biological analysis.

Computational Modelling

Computational models that have been validated against relevant experiments allow for multiple virtual experiments to be conducted in a cost-efficient, repeatable, well-controlled manner. They allow researchers to alter parameters related to geometry, materials, and environment, as well as understanding behaviours at locations where we cannot physically measure. Computational models can help design bespoke experimental rigs and mounts, helping to predict locations of potential failures, and therefore aid in the design/re-design process.



Materials Testing

We have a collection of platforms for testing the performance of various materials. The screw-driven uniaxial material testing machine with multiple bespoke fixtures can perform material and structural characterisation of soft and skeletal tissues, and implant and fixation systems. The servo-hydraulic dual axis material testing machine and the micromechanical testing system can carry out high-precision compression, tension, shear, and torsion tests, in static as well as dynamic loadings, to a range of structural and biological materials. Our facilities and expertise allow for the testing of materials, components, and devices according to industry standards. We also have extensive experience in developing bespoke testing protocols when standards are not available or cannot cover a specific requirement.

Centre Research Summary

Over the last 10 years, the Centre has focused on a wide range of clinical priorities, with the cross-cutting themes of mitigation, treatment, and rehabilitation. The below provides a short summary of just some of the exciting findings that have been made at the Centre to date.

Musculoskeletal and Extremity Injury

Foot and ankle injuries:

Severe foot and ankle (F&A) injuries were a common injury pattern identified for mounted troops (those in vehicles, rather than on foot), secondary to an explosive insult of the vehicle in recent conflicts. Using AnUBIS we have shown that different postures of the knee and foot angle produce different probabilities of injury and that this should be considered in vehicle design and tests [1]. We have also tested commercially available mats and identified their protective capacity.

CBIS is working on producing a clinical decision tool to indicate which patients will most benefit from an ankle foot orthosis (AFO), so that the, often painful, attempts at limb salvage rehabilitation in unsuitable patients are prevented. This is complemented by work to understand the mechanism by which the AFO reduces the load seen by the foot and ankle, combining gait data with computational models.

Lower limb injuries:

CBIS' investigations into how bone fractures were affected by a subject's environment (e.g. in a vehicle or in cover, compared with free-field) have shown that lower limb injuries in survivors were significantly increased for those in cover [2]. The posture and position within a vehicle also had an impact on the injuries, both in terms of pattern and severity. CBIS' work on the effect of in-vehicle posture on injury is widely published [1,3] and disseminated, and is being considered by vehicle manufactures and in retrofitting of the current UK armoured vehicle fleet.

Spinal injury:

Spinal injuries are common in underbody blast. To better understand the mechanism of spinal injury, in blast, CBIS identified the patterns of injury in the British victims of IED strikes on vehicles [4]. Injuries are caused by forces directly through the structure of the vehicle, but also due to the legs being thrown up by the deforming floor during the blast. The data from the study is being used to inform experimental models of how the spine fails during blast and computational models that can predict injury to the spine based on different postures. These models will be used to improve assessment of the protective capability of vehicles (and seats) and personal protective equipment.

Pelvic injury:

Pelvic vascular injury for explosive insult casualties is a principal risk factor for increased mortality. CBIS has influenced the awareness of the positioning of the pelvic binder in Role 1 [5]. The positioning is taught in Battlefield Advanced Trauma Life Support (BATLS) courses and has now also been adopted by the US military.

The mechanism of injury had not previously been investigated in a physical model so CBIS have utilised a cadaveric small-animal model of pelvic blast injury. The model has shown that lower limb flair is necessary for an unstable pelvic fracture with vascular injury to occur [6]. Further modelling has shown that high velocity sand blast can result in significant injury, including traumatic amputation, perineal wounding, and pelvic fracture [7]. Future protective strategies should be developed towards protecting against high velocity sand blast to mitigate this mechanism of injury and to provide protection which limits lateral displacement of the sacroiliac joints of the pelvis [8].

Amputees:

There are over 200 UK veterans with lower limb amputations. A recent survey study conducted by CBIS showed that the main factor affecting rehabilitation, from the perspective of amputees, physiotherapists, and prosthetists, is socket fit [9]. The survey compares clinician and amputee perceptions and found that amputees focused on function and experience, physiotherapists were concerned about gait re-education, and prosthetists discussed the ability to adjust sockets. It noted that the interpretation of “good socket fit” varied between individuals.

Our biomechanical analysis has shown why unilateral below knee amputees get accelerated arthritis on their intact limb [10]. This will now be used to design better prostheses and surgical interventions. By modelling loading patterns through sockets and prosthetics we are understanding why such high rates of osteoporosis are observed.

Through-knee amputees have a significantly higher function than above-knee amputees. We have developed an implant to enable above knee amputees to bear load to re-create this function [11].

Heterotopic ossification:

A prevalent outcome of traumatic amputation due to blast is heterotopic ossification (HO), which is bone formation in soft tissues, away from the skeleton. CBIS has developed models to study HO. One model designed, developed, and calibrated *in vitro* experimental platforms which expose cell cultures to conditions that mimic a blast event from a landmine/IED [12]. This allows researchers to study cell health and the cellular response to a blast.

In addition, we have developed a cadaveric blast injury rodent model to replicate the injuries seen due to IED detonations in enclosed spaces [13]. This model is being translated into a survivable rodent model to help investigate the mechanisms of diseases such as HO which follow blast injury. Given that HO can cause swelling and pain, and can impact quality of life, determining mechanisms involved in its onset is pivotal to design targeted treatments and interventions.

Hearing Loss

Auditory processing disorder (APD) afflicts many veterans due to noise exposure and blasts. APD refers to an impairment with the processing of auditory information in the brain. Affected individuals have major problems with understanding speech in background noise, and there is currently no treatment for the condition. Current hearing aids, in particular, do not help with this issue since they amplify all environmental sound, including background noise.

The work in CBIS regarding hearing loss focussed on developing novel technology to aid people with APD in better hearing in noisy environments. We showed that visual as well as tactile signals that accompanied auditory information could improve speech-in-noise comprehension. We also showed that critical information regarding auditory processing, such as attention to speech, can be decoded from non-invasive brain measurements and be used in closed-loop hearing aids. Such closed-loop hearing aids can steer a user to a target sound source, such as a particular speech signal, and thus make it easier for them to understand that speech.

Head and Brain Injury

Blast traumatic brain injury (bTBI) was a common injury in the Iraq and Afghanistan conflicts. The mechanisms and pathology of bTBI are less well understood than TBI caused by blunt or penetrating trauma. One potential mechanism is cerebrospinal fluid (CSF) tensile failure which could cause brain deformation. A CBIS study showed that rapid head motion because of a blast wave is the key mechanism for CSF tensile failure [14]. These findings suggest the need for mitigation strategies that prevent head motion caused by blast loading and the team will use this information in the consideration of protective equipment design.

There are no known treatments to prevent or limit the effects of bTBI and so there is a need to find treatments that stop or diminish the cognitive deficits that can be caused by bTBI, and that improve recovery. CBIS has investigated the use of xenon (an inert gas used as a general anaesthetic) in an in vitro model of bTBI and has shown that the xenon treatment starting at 1 hour after the trauma, significantly limits injury progression [15].

Causes of Death/Next Level of Survivors/Clinical Scoring and Civilian Correlates

CBIS is very interested in clinical scoring [16]. Traditionally, mathematical scoring systems based on previously treated casualties have been used to assess the risk of death following injury. As such they are retrospective in nature, and as medical advances are made and survival rates improve, all scoring systems will become inaccurate; until a stage is reached where further advances cannot improve survival rates. Further improvements in survival can then only be made with mitigation rather than treatment and this will not be detected with the scoring systems. There is also the problem of "unsurvivable injuries". Some will always be unsurvivable – decapitation for example – but some, particularly very high bilateral leg amputations had survival rates of 1% or less in previous conflicts, but now have survival rates above 50%, and so need to be reclassified. Therefore, as mitigation and treatment advances are made, traditional scoring systems need to be revised. CBIS is pushing this area.

Casualties experience different injury patterns after blast, depending on the environment [17]. The common cause of death for a casualty on foot during a blast is an unstable pelvic fracture which results in blood loss. Treatment should focus on early pelvic haemorrhage control. For those in a vehicle during the blast (under body blast), the fatalities are usually from injuries to the head and torso. Torso injuries, including those to the heart and great vessels, are the strongest indicators of under body blast mortality [18].

Torso Trauma

A key area of understanding torso trauma from blast events, is understanding blast lung. Studies in CBIS focused on microstructural changes that occur within the mammalian lung when subjected to blast [19]. Blast lung in the clinical setting can be transient, therefore it is important to characterize the non-instantly fatal doses of blast. The study showed focal sites of injury following exposure to the blast model, which highlighted the need for better understanding of such focal injury and its zone of influence.

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Collaboration

The Centre benefits significantly from its close collaborations with many organisations. These range from military organisations who provide data which informs the research, to industry partners who can translate the findings for the benefit of the military, and charities who work with those that the Centre is ultimately trying to benefit.

UK Military and Defence Medical Services

The Centre has been privileged to work in full cooperation with the UK military and Defence Medical Services since the establishment of Imperial Blast in 2008, and then onwards into CBIS from 2011. Over the course of Imperial Blast and CBIS, twelve military personnel have been directly embedded in the Centre to undertake short projects, Masters degrees or PhDs. In addition, many have also had direct roles in the supervision of researchers and the strategic direction of the Centre. The support provided by the military has been incredibly valuable, and highlights the importance, and direct impact, of the work that is undertaken. There is a two-way flow of information, with the research being directly informed by real-world data from injuries and the research then translating into improvements for military personnel (for example through personal protective equipment or treatments).

Defence Science and Technology Laboratory (Dstl)

Some members of the Centre work closely with Dstl, a UK government agency for applying science and technology to the defence and security of the UK. Projects have focussed on developing experimental and computational models of blast injury and evaluating protective equipment for mitigation of injuries to military personnel. The collaboration has resulted in joint publications and working together on Government committees as well as jointly participating in public inquiries and inquests

Defence Equipment and Support (DE&S)

Members from the Centre have been engaging with DE&S, the UK's MOD agency for defence equipment and support, to ensure that their studies on blast injury and its protection through protective equipment are relevant, appropriate, and valuable to DE&S.

ADVANCE Study

The ArmeD SerVices TrAuma RehabilitatioN OutComE (ADVANCE) Study is a longitudinal study which is investigating the outcomes of battlefield casualties from the UK Armed Forces who were deployed to Afghanistan between 2002 and 2014. It looks at physical and psycho-social outcomes. The study is a collaboration between Imperial College London, King's College London, and the Defence Medical Rehabilitation Centre (DMRC). Professor Anthony Bull is a member of the study's Project Board which ensures strong links between the Centre and the study. Some members of the CBIS Advisory Board are also members of the ADVANCE Charity Board of Trustees. ADVANCE is a natural progression from CBIS, where the focus in ADVANCE is on outcome data and the focus in CBIS is on fundamental through to translational science and engineering, including interventions.

United States Military

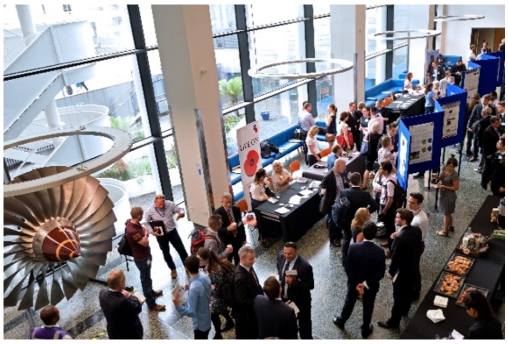
In 2017-2018 Lieutenant Colonel Dan Stinner from the US Army was based at the Centre as a Visiting Researcher. Lt Col Stinner is an orthopaedic surgeon (now working at Vanderbilt University Medical Centre) who worked on a variety of research projects whilst at the Centre, including the effect of blast waves on cellular response and the efficacy of foot and ankle orthoses on functional outcomes. Whilst here, he helped to arrange the annual Networking Event, which that year (2017) focused on UK-US collaborations. The important connections that the Centre has made through Lt Col Stinner and other colleagues continue to develop, and we have had a number of collaborations in place across the Centre over the last few years.

Dissemination

The Centre believes that it is important to disseminate research outputs and impact to a wide audience, and as such it undertakes to engage with interested parties through a variety of means. This includes engaging with researchers, clinicians, policy makers, charities, humanitarian organisations, and the general public. Over the last 10 years the Centre has been involved in, and hosted, a number of events and initiatives to promulgate its knowledge. Some examples are provided below.

Blast Injury Conference

In the early days of the Centre, we hosted Annual Networking Events which attracted researchers from across Imperial College and collaborating organisations to visit the Centre to learn about the work in the field of blast injuries. In 2017, the event had grown to include a partnership with the US Military and welcomed many colleagues from the United States to collaborate and share knowledge. In 2018, the Centre decided to rebrand the Annual Networking Events, given that the events had become much larger and more international. Thus, the first Blast Injury Conference took place. The conference has grown year on year, with 220 delegates and a visit from His Royal Highness Prince Harry the Duke of Sussex in 2019, expanding to 789 delegates for the 2021 conference which was held online. This conference has become an important event to bring clinicians, engineers, scientists, military personnel, industry, charities, humanitarian organisations, and all of those interested in blast injuries together over two days to discuss issues, debate topics, and ultimately to promote potential collaborations. Planning for the 2024 event is well underway.



Societal Engagement

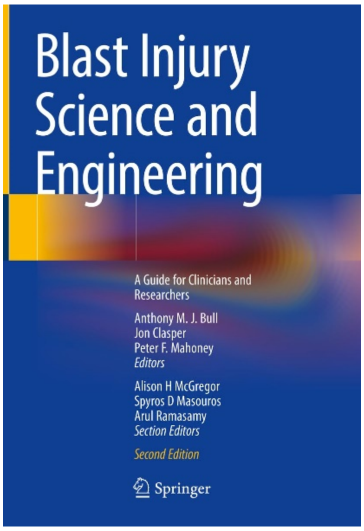
Over the years, CBIS members have been involved in many activities that are specifically focussed on engaging the public with research. The team have taken part in many of the annual Imperial Festival/Great Exhibition Road Festivals, the Royal Institution of Great Britain’s Family Fun Day, Science Museum Lates, Twitter Conferences, and have even hosted a podcast called Fragments which discussed research and issues around blast injuries. All these wonderful activities offer the opportunity for CBIS PhD students, postdocs, administrative staff and academics to find entertaining and fun ways to discuss blast injury research with the public in different settings. These events have always received positive feedback.

Surgical Training Course

In 2016, the Centre hosted a Surgical Training Course, supported by Find a Better Way and Smith & Nephew, which delivered bespoke training to trauma surgeons from 10 different countries around the world. The course was the ideal vehicle to transfer lessons learned in military conflict to the civilian domain. It also provided an opportunity to deliver measurable benefit to patients and the public in landmine afflicted countries and across the Developing World.

Blast Injury Science and Engineering Book

Working together with external collaborators, Centre academics and researchers were involved in the production of the Blast Injury Science and Engineering textbook in 2015. Following the success of the first edition, the Centre produced a second edition in 2022, bringing the textbook up to date with current advances in the blast injury field with most chapters being totally rewritten and a whole new section added. The textbook is designed to help the spectrum of researchers from all backgrounds who seek to conduct science and engineering-based research on blast injuries. The contents of the book are a consequence of our experience in working in an interdisciplinary environment.



Visits

The Centre has had the privilege of welcoming many visitors and showing them round the facilities, meeting researchers and discussing the research. We have had visits from various teams from the Royal British Legion, the UK military, Members of Parliament, Members of the House of Lords, and even a couple of royal visits. Centre members are passionate about discussing their research and the impact that it can have on those affected by blast, and our visitors all find the events highly engaging.

CBIS Alumni – Where are they now?

Dr Nic Newell – Former Centre PhD student, Postdoc and now Lecturer in the Department of Bioengineering

In September 2021 I was appointed a Lecturer in the Department of Bioengineering. Having, been one of the first PhD students in the Centre, then a postdoc, and now a Lecturer supervising CBIS PhD students, my career has progressed alongside CBIS, with CBIS being a major influence throughout.

My PhD started a few months before CBIS was initiated (when we were still called Imperial Blast). It was an extremely exciting time working closely with military medics and learning a huge amount from the engineers that I was working with. I've never felt so motivated to learn quickly and scramble to undertake research that could impact outcomes on the battlefield. It was special to be involved in that team and I think we conducted some important research. Initially we focused on understanding whether combat boots offered any protection to occupants of vehicles during under-body blast incidents and whether the level of protection offered by assorted combat boot designs differed. The research then moved on to understanding how well car crash dummies represented human response when being used to assess vehicle designs or mitigation technologies, how posture affected injury risk, and how blast mats could be used to protect occupants' lower limbs. Alongside this we were developing computational models of the lower limb (and surrogates), which we could use as tools to understand injury mechanisms and to develop mitigation strategies. Many of these outputs have been described in previous annual reports.

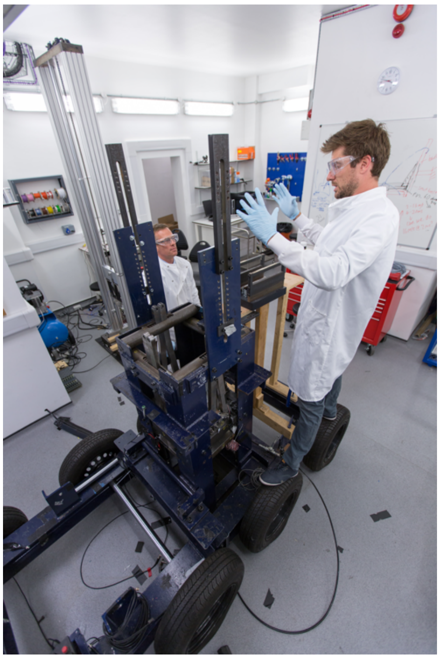


Figure 1: Dr Nic Newell (right) and Prof Anthony Bull (left) working on the AnUBIS

The techniques that I learnt during my PhD, and later my postdoc in CBIS has served as a platform upon which I am building my current research efforts that focus on spine biomechanics. My current research has three main themes, the first aligns well with the CBIS work I was involved in, to better understand spinal injury with a particular focus on injuries sustained to intervertebral discs. The second is around spinal deformities, and finally the third focuses on surgical treatments, particularly for patients with lower back pain. My group now has four PhD students and a postdoc with new recruits starting soon.

I think I, and now my research group, serve as examples of outcomes from CBIS that maybe are not always well documented. The opportunities that CBIS gave me to develop research skills are undoubtedly now being leveraged in other areas, that will have impact beyond blast injury.

Iain Rankin, MBChB BSc (MedSci) MSc MRCS(Ed) PhD DIC

I joined the Centre for Blast Injury Studies in 2018 as a PhD candidate under the supervision of Dr Spyros Masouros and Professor Jon Clasper. I applied to the unit due to its reputation as a world leading centre in the study of blast injury, with an environment which fosters multidisciplinary collaborations between surgeons, engineers, and scientists. I wanted to undertake clinically driven research, which concentrated on priority areas that reflected the most significant conditions caused by blast injury. In recent military conflicts, explosive blast was the most common cause of wounding and death. Where blast resulted in injury to the pelvis of an on-foot casualty, the mortality rate was high. The mechanism of injury by which this occurs was not known. As such, my research sought to understand the pattern and mechanism of this devastating injury and to develop mitigative strategies.

I started with an analysis performed on battlefield data, which identified pelvic vascular injury as the cause of death in these casualties. Furthermore, it identified displaced pelvic fractures (with lateral displacement of the sacroiliac joints showing the strongest association), perineal wounding, and traumatic amputation to be the pattern of injury associated with these lethal vascular injuries. Following this, my research then focused on identifying the mechanism of these injuries. Hypothesised mechanisms of injury were investigated using several cadaveric animal models of blast. These investigations showed rapid outward movement of the lower limbs ('limb flail'), caused by the blast wave, to be necessary for displaced pelvic fractures with vascular injury to occur. High velocity sand ejecta, as propagated by blast ('sand blast'), showed correlation with increasing velocity and injury patterns of worsening severity across the trauma range. This included the associated injuries of perineal wounding and traumatic amputation. From these investigations, lower limb flail and high velocity sand blast were identified as the mechanisms of injury of blast to the pelvis.

The final step in my research was to develop mitigative strategies against these mechanisms of injury. I went on to test novel pelvic protective equipment, developed to limit lower limb flail in a cadaveric animal model of blast. This resulted in a reduction of pelvic fractures and elimination of pelvic vascular injury. Protective shorts were examined in a human cadaveric model and shown to markedly reduce the severity of injury from high velocity sand blast.

I was pleased that my PhD thesis research was recognised by the US Department of Defense as 'significant research in blast injury prevention, mitigation, and treatment' and it has been presented nationally and internationally at orthopaedic, engineering, and military conferences. The work has resulted in the publication of multiple original research articles in high impact factor journals and three book chapters. The protective equipment proposed from this research may save lives.

Collaborative authors towards parts of this research include Dr Thuy-Tien Nguyen, Dr Dilen Carpanen, Miss Louise McMenemy, Dr Alastair Darwood, and Mr John Breeze.

Following my PhD studentship at the Centre, I am working as a Senior Registrar in Trauma and Orthopaedic Surgery in the North of Scotland Deanery and believe that my time at the Centre was critical in developing my skills as a researcher. I continue to apply the principles of trauma biomechanics and have since gone on to publish several further research articles. I am currently preparing for my FRCS (Tr & Orth) examinations and am working towards completing my training to become a Consultant in Trauma and Orthopaedic Surgery, with a specialist interest in trauma surgery and research.

Exemplar Research Findings

The following pages provide short overviews of some of the Centre's publications from 2022. These are given as examples of the breadth of work being undertaken within the Centre.

These papers represent a fraction of the work that our researchers are doing as many researchers are also working on projects outside of CBIS. Key highlights from this year are the two ADVANCE Study papers that are associated with the Centre (pages 23 and 24). These are the first of what are sure to be many important outputs from ADVANCE and have shown that there are real differences in physical and mental health outcomes between different groups of the combat injured armed forces personnel. This focuses our minds on rehabilitation and long-term medical care, and we have many outputs over the past year in rehabilitation of military amputees (pages 31-36).

Also, a project was funded by the 'Strategic Priorities Fund - Evidence-based policy making' (from Research England through the College) to generate the evidence to show that biofidelic backing is required when testing soft body armour. The results, obtained for two common ballistic fabrics across six different projectiles, support the use of a biofidelic backing material in ballistic assessment of soft body armour. A paper was published in the Human Factors Journal (page 37) and the findings have been communicated to the GEMS (Government Experts on Mitigation Systems) meeting and will be sent to contacts in Defence Equipment and Support (DE&S) and Defence Research and Development Canada (DRDC), who sit in the STANAG (Standardization Agreements) committee (2920) for ballistic protection. This project is a nice example of CBIS progression: we initially focused mainly on primary and tertiary blast and then, with the support of our main funder and Advisory Board, created experimental capability in secondary blast with our gas gun. This experimental apparatus enabled the testing of these ballistic fabrics. We have also published other studies on protection, including floormats (page 41) and helmets and goggles (page 42).

Association between combat-related traumatic injury and cardiovascular risk

Boos CJ, Schofield S, Cullinan P, Dyball D, Fear NT, Bull AMJ, Pernet D, Bennett AN (2022)

Heart (108), 367-374

The Centre for Blast Injury Studies plays a collaborative role in the ADVANCE Study, the 20 year cohort study of the UK military major war wounded from Afghanistan. This first results paper from the study is investigating the relationship between combat-related traumatic injury and two indicators of cardiovascular risk: metabolic syndrome and arterial stiffness.

Until now, the relationship between combat-related traumatic injury and future risk of developing cardiovascular disease, such as heart attack and stroke, has been uncertain. ADVANCE is the first study to look at this relationship on a relatively large scale and over a long period of time. This publication describes the first cardiovascular risk findings from ADVANCE baseline data analysis - data that was collected during each participant's first ADVANCE visit.

The results show that the occurrence of metabolic syndrome and arterial stiffness was higher in the injured group compared to the non-injured. This wasn't explained by differences in age or service rank between the two groups. However, these differences are not great enough to warrant any medical treatment at this stage, and these factors will be monitored in all participants over the course of the study.

Combat-related traumatic injury increases markers of cardiovascular risk

- The notable differences between the injured and non-injured were higher waist circumference, higher triglycerides, and lower HDL cholesterol in the injured group.
- There were no differences between the injured and uninjured groups in blood sugar or blood pressure.
- Arterial augmentation index, one of the main measures of arterial stiffness, was marginally, but significantly, greater in the inured compared to the uninjured group. However, another measure of arterial stiffness, known as pulse wave velocity, was no different in the two groups.
- Worse injury severity, lower age and lower socioeconomic status were also shown to be associated with higher incidence of metabolic syndrome and arterial stiffness.

Mental health outcomes of male UK military personnel deployed to Afghanistan and the role of combat-injury: The ADVANCE cohort study

Dyball D, Bennett AN, Schofield S, Cullinan P, Boos CJ, Bull AMJ, Wessely S, Stevelink SAM, Fear NT. (2022)

Lancet Psychiatry (9), 547-554

The Centre for Blast Injury Studies plays a collaborative role in the ADVANCE Study, the 20 year cohort study of the UK military major war wounded from Afghanistan. Mental health outcomes research is led by colleagues from King's College London.

The long-term mental health outcomes of UK Armed Forces personnel who sustained serious combat injuries during deployment to Afghanistan are largely unknown. ADVANCE is the first study to look at these outcomes on a relatively large scale and over a long period of time. The aim of this piece of ADVANCE research was to find out whether the injured group (who have experienced combat-related traumatic injury) and the uninjured comparison group have differences in terms of their mental health outcomes. We looked at depression, anxiety, PTSD, and mental health multimorbidity (PTSD with depression and/or anxiety) by analysing the ADVANCE baseline data collected from the cohort.

Our findings showed that the injured group had greater rates of depression, anxiety and PTSD compared to the uninjured group. However, the type of injury seemed to have a significant impact. Participants with amputation related injuries had very similar rates of mental health problems compared to the uninjured group, whereas those with non-amputation injuries had significantly higher rates of mental health problems. We also showed that in both the injured and uninjured groups, the rates of PTSD were greater compared to the UK general population and both represented groups with increased psychological burden from multimorbidity.

One of the main questions that arises from these findings is around the differences in outcomes between the amputees and the injured non-amputees. Next steps include looking into the reasons for these differences. Follow-up data on mental health outcomes will also be analysed over the 20-year duration of ADVANCE.

Mental health outcomes of the ADVANCE study cohort eight years post injury

- Rates of PTSD, anxiety and depression were higher in the injured vs. uninjured group: Depression: 23.6% in injured vs. 16.8% in uninjured. Anxiety: 20.8% in injured vs. 13.5% in uninjured. PTSD: 16.9% in injured vs. 10.5% in uninjured.
- Rate of mental health multimorbidity was also higher in the injured vs. uninjured group (15.3% vs 9.8%).
- Participants with amputations reported very similar rates of mental health issues compared to the uninjured group. However, participants with non-amputation injures were up to twice as likely to suffer from mental health issues.

A critique of injury scoring systems when used for blast injuries: A narrative review with recommendations for future work

Hazell GA, Pearce AP, Hepper AE, Bull AMJ (2022)

Brit J Anaesth (128), e127 - e134

Injury scoring systems can be used for triaging, predicting morbidity and mortality, and prognosis in mass casualty incidents. Recent conflicts and civilian incidents have highlighted the unique nature of blast injuries, exposing deficiencies in current scoring systems. CBIS has led on much of this work and has, over time, recognised that scoring systems need an overhaul. Recent work on the Birmingham Pub Bombing Inquest and the Manchester Arena Bombing Inquiry led the team to capture their learning in this review article and opinion piece.

We classified and described the key deficiencies with current systems used for blast injury. The reliable prediction of mortality on an individual basis is inaccurate, thus limiting their use. Other limitations include the saturation effect (where scoring systems are unable to discriminate between high injury score individuals), the effect of the overall injury burden, lack of precision in discriminating between mechanisms of injury, and a lack of data underpinning scoring system coefficients. Other factors influence outcomes, including the level of healthcare and the delay between injury and presentation. We recommend that a new score incorporates the severity of injuries with the mechanism of blast injury. This may include refined or additional codes, severity scores, or both, being added to the Abbreviated Injury Scale for high-frequency, blast specific injuries; weighting for body regions associated with a higher risk for death; and blast-specific trauma coefficients. Finally, the saturation effect (maximum value) should be removed, which would enable the classification of more severe constellations of injury. A nearly accurate assessment of blast injury may improve management of mass casualty incidents.

Future work from the Centre will address these deficiencies and seek to work with partners to develop a more appropriate scoring system.

Current injury scoring systems are not appropriate for use in blast injuries

- Blast injuries are common in mass casualty incidents.
- The unique nature of blast injuries exposes major deficiencies in current scoring systems used for triage and prognosis in mass casualty incidents.
- 'Unexpected' survivors are disturbingly common after mass casualty incidents involving blast injury.
- Current scoring systems need to be amended to include the mechanism of injury, refine/add codes for specific injuries, weighting of scores for specific body regions, and the removal of the upper limit to allow scoring to more severe injuries.

Focused assessment with sonography in trauma (FAST) performance in paediatric conflict injury.

Sargent W, Bull AMJ, Gibb I. (2022)

Clinical Radiology (77), 529-534

Through the close collaboration with Defence Medical Services, CBIS can access expertise and data derived from in-theatre experience. A powerful dataset is the JTTR (Joint Theatre Trauma Registry) which gives access to a unique cohort of blast-injured children. The aim of this study was to evaluate the efficacy of a type of medical imaging which is easily available (Focused Assessment with Sonography in Trauma; FAST) for penetrating abdominal injuries in children, which is uncommon in paediatrics outside of conflict zones, but much more common in warfare. A positive result identifies a child at risk of rapid deterioration.

FAST and computed tomography (CT) abdomen findings were compared for 98 children who presented to Camp Bastion during the war in Afghanistan in 2011. 2011 was chosen because of the large number of children injured and the availability of the CT scans. FAST performance was compared to the reference standard of free fluid detected on CT.

Of the 98 patients, 20 had free fluid on CT and 15 were FAST positive. Fourteen of the 98 (14%) had penetrating wounds to the abdominal cavity. For the whole cohort FAST sensitivity was 65% (41-85%) and specificity 97% (91-100%). For those with penetrating abdominal injury sensitivity was 64% (31-89%) and specificity was 100% (40-100%). In total, 45% arrived at the same time as another casualty, and 30% arrived with other injured children.

The key finding in this study was that the readily available FAST imaging performance in this population was similar to that reported in the context of paediatric blunt trauma, with high specificity for intra-abdominal free fluid. This is the first time this has been demonstrated in a cohort containing children with penetrating abdominal trauma and is directly relevant to the military experience, where treatment of children injured in conflict has formed a significant part of the caseload. A substantial proportion of children presented as part of a group, necessitating simultaneous triage of multiple injured patients.

Therefore, FAST has a role to play in conflict medicine and mass casualty scenarios where rapid access to CT may not be feasible and so consideration should be given to training of operators and the provision of scanning technology.

Focused Assessment with Sonography can be used in paediatric penetrating trauma

- FAST imaging performance is similar to that reported in paediatric blunt trauma.
- Frequently children injured in blast present as a group, necessitating a triage tool.
- FAST can be used as this triage tool.
- We recommend that FAST should be reflected in future paediatric imaging guidelines.

Prediction of in vivo hip contact forces during common activities of daily living using a segment-based musculoskeletal model

Amiri P, Bull AMJ. (2022)

Front. Bioeng. Biotechnol (10), 3389

Our musculoskeletal modelling work enables mechanical signals of various pathologies due to blast – and the long-term effects thereof – to be analysed and understood. This opens the door to mechanical therapies such as physiotherapy, prosthetics, and other assistive devices.

One of the key outputs of musculoskeletal models are the joint contact forces. This enables the analysis of conditions such as osteoarthritis (the wear and tear of joints) and bone resorption (osteoporosis). Joint contact forces cannot normally be directly measured, which is why computer (musculoskeletal) models are used.

In this study, the models developed by the Centre are validated for hip joint contact forces. This is enabled by a seminal study in the literature in which several participants undergoing hip joint replacement surgery have an instrumented joint replacement implanted which directly measured their hip joint contact force. This was used to validate the model-derived hip joint contact forces.

Uniquely in this study, the work analysed not only walking ("gait analysis"), but also other activities of daily living, such as going up and down stairs, standing up, and sitting down.

The study was able to quantify the hip joint contact forces to a high degree of accuracy, but only using a new objective function, which is the mathematical problem formulation as in Figure 2.

$$\min J = \sum_{i=1}^{163}\left(\frac{F_i}{F_{imax}}\right)^2 + \alpha\,\frac{|\boldsymbol{HCF}|}{BW}$$

$$0 \le F_i \le F_{imax}\,,\quad i = 1, \ldots, 163$$

$$subject\ to:$$

$$\begin{bmatrix} \sum_{l=1}^{L} F_l \cdot \boldsymbol{n}_{lm} - \sum_{k=1}^{K} F_k \cdot \boldsymbol{n}_{k(m-1)} + \boldsymbol{J}_m - \boldsymbol{J}_{m-1} \\ \sum_{l=1}^{L} F_l \cdot \boldsymbol{n}_{lm} \times \boldsymbol{r}_{lm} - \sum_{k=1}^{K} F_k \cdot \boldsymbol{n}_{k(m-1)} \times \boldsymbol{r}_{k(m-1)} - \boldsymbol{d}_m \times \boldsymbol{J}_{m-1} \end{bmatrix} = \begin{bmatrix} M_m \boldsymbol{E}_{3\times3} & \boldsymbol{0}_{3\times3} \\ M_m \tilde{\boldsymbol{c}}_m & \boldsymbol{I}_m \end{bmatrix} \begin{bmatrix} \boldsymbol{a}_m - \boldsymbol{g} \\ \ddot{\boldsymbol{\theta}}_m \end{bmatrix} + \begin{bmatrix} \boldsymbol{0}_{3\times1} \\ \dot{\boldsymbol{\theta}}_m \times \boldsymbol{I}_m \dot{\boldsymbol{\theta}}_m \end{bmatrix}$$

Figure 2: Novel objective function to obtain muscle and joint forces using CBIS' musculoskeletal modelling software

Hip joint contact forces can be accurately predicted using a novel objective function

- Musculoskeletal models can obtain internal forces that cannot be directly measured.
- A novel mathematical formulation of the objective function was able to accurately quantify hip joint contact forces, validated by direct measurement.
- This is the first study to validate hip joint contact forces for a large range of activities of daily living.

Pathological slow-wave activity and impaired working memory binding in post-traumatic amnesia

Mallas EJ, Gorgoraptis N, Dautricourt S, Pertzov Y, Scott G, Sharp DJ. (2022)

Journal of Neuroscience 42 (49), 9193-9210

How do we remember what was where? The mechanism by which information (e.g., object and location) is integrated in working memory is a central question for cognitive neuroscience. Following significant head injury, such as during blast injury, many patients will experience a period of post-traumatic amnesia (PTA) during which this associative binding is disrupted. This may be because of electrophysiological changes in the brain. Using a precision working memory test and resting-state EEG, we show that PTA patients demonstrate impaired binding ability, and this is associated with a shift toward slower-frequency activity on EEG. Abnormal EEG connectivity was observed but was not specific to PTA or binding ability. These findings contribute to both our mechanistic understanding of working memory binding and PTA pathophysiology. This work is now being extended within the UKDRI (UK Dementia Research Institute) to assess binding deficits and electrophysiological changes in neurodegenerative conditions, including comparative assessment of the mechanisms of working memory impairment across clinical groups.

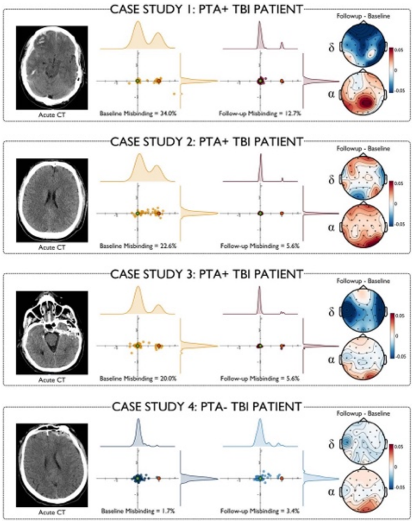


Figure 3: Individual case studies. CT head scans at admission are shown on the far left of each case study panel. The distribution of responses in correctly identified trials in the precision spatial working memory task are shown for baseline and follow-up in the middle panels. Topoplots (right) represent changes in δ (top) and α (bottom) between baseline and follow-up.

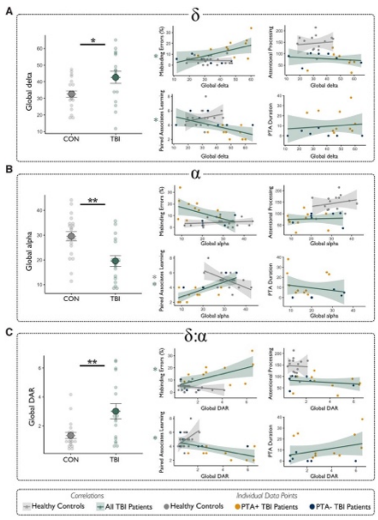


Figure 4: Relationship between global normalized power and cognitive impairment. ***A****, Global δ power was increased in the TBI group compared with healthy controls and correlated with proportion of misbinding errors and performance on the paired associates learning task.* ***B****, Global α was significantly decreased in TBI patients compared with healthy controls, and significantly correlated with the performance on the paired associates learning task.* ***C****, Global DAR was significantly increased in TBI patients compared with healthy controls and correlated with the proportion of misbinding errors, and performance on the paired associates learning task. **$p < 0.01$. *$p < 0.05$.*

EEG Changes in Post-Traumatic Amnesia

- Blast injury can cause significant head injury and Post-Traumatic Amnesia (PTA)
- Short-term visual working memory binding is significantly and transiently impaired during a period of post-traumatic amnesia following severe head injury.
- Pathological slowing of cortical oscillatory activity, indicated by a significant increase in the delta to alpha ratio is observed in the acute period following traumatic brain injury. This is significantly associated with impairment in visual working memory binding deficits.
- Working memory and electrophysiological abnormalities normalised at 6-month follow-up.

Automation and standardization of subject-specific region-of-interest segmentation for investigation of diffusion imaging in clinical populations.

Azor AM, Sharp DJ, Jolly AE, Bourke NJ, Hellyer PJ. (2022)

PLoS One 17 (12)

Diffusion weighted imagining (DWI) generates contrast in magnetic resonance imaging (MRI) through the diffusion of water molecules and is key in clinical neuroimaging studies. Diffusion magnetic resonance imaging (dMRI) is widely used to analyse group-level differences in white matter but suffers from limitations. Region of Interest (ROI) analyses in native diffusion space can help overcome these limitations, with manual segmentation still used as the gold standard. However, robust automated approaches for the analysis of ROI-extracted native diffusion characteristics are limited. Subject-Specific Diffusion Segmentation (SSDS) is an automated pipeline that uses pre-existing imaging analysis methods to carry out white matter investigations in native diffusion space, while overcoming the need to interpolate diffusion images and using an intermediate T1 image (highlighting fat tissue within the body) to limit registration errors and guide segmentation.

SSDS uses common registration techniques and predefined atlases to make automated segmentation stable in native diffusion space, maintaining high correspondence with FA (fractional anisotropy) values obtained from manual segmentation of ROI, and providing a reproducible pipeline capable of replacing manual segmentation of ROIs on parametric maps in clinical subject-level investigations. SSDS shows high test-retest reliability across subjects and visits for both the FA value calculated and the size of the tracts.

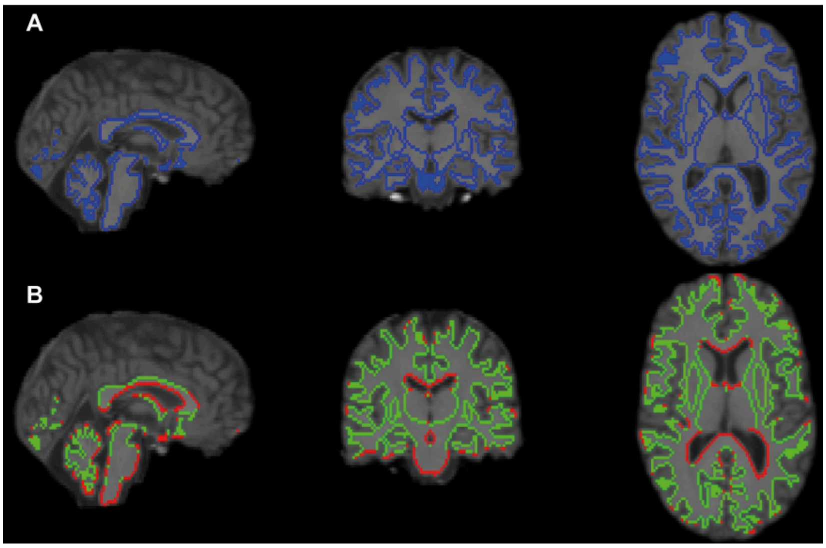


Figure 5: Example of boundary segmentation. A) Boundary of the WM. The blue line is the binary mask. The T1 image is in native diffusion space. B) Boundary of the WM/CSF and WM/GM. The red line is the mask of the WM/CSF boundary, and the green line is the mask of the WM/GM boundary. The T1 image is in native diffusion space.

The paper suggests using SSDS for clinical diffusion tensor imaging studies where individual segmentations and subject-specific diffusion metric estimations might be more revealing than group-level analyses. SSDS can therefore replace manual ROIs, is an automated and reliable pipeline, standardised for more homogenous and reproducible methodology across studies.

Automation and standardisation of diffusion imaging in clinical populations

- Subject-specific diffusion segmentation (SSDS) Is an automated pipeline that uses pre-existing imaging analysis methods to carry out white matter investigations.
- SSDS should be used for diffusion tensor imaging studies where individual segmentations and subject-specific diffusion metric estimations might be more revealing than group-level analyses.
- SSDS could replace manual ROIs as an automated and reliable pipeline.

Detection of glial fibrillary acidic protein in patient plasma using on-chip graphene field-effect biosensors, in comparison with ELISA and single-molecule array

Xu L, Ramadan S, Akingbade OE, Zhang Y, Alodan S, Graham N, Zimmerman KA, Torres E, Heslegrave A, Petrov PK, Zetterberg H, Sharp DJ, Klein N, and Li B. (2022)

ACS Sens 7 (1) 253-262

Glial fibrillary acidic protein (GFAP) is a discriminative blood biomarker for many neurological diseases, such as traumatic brain injury. Detection of GFAP in buffer solutions using biosensors has been demonstrated, but accurate quantification of GFAP in patient samples has not been reported, yet in urgent need. Herein, we demonstrate a robust on-chip graphene field-effect transistor (GFET) biosensing method for sensitive and ultrafast detection of GFAP in patient plasma. Patients with moderate–severe traumatic brain injuries, such as those from blast injury, defined by the Mayo classification, are recruited to provide plasma samples. The binding of target GFAP with the specific antibodies that are conjugated on a monolayer GFET device triggers the shift of its Dirac point, and this signal change is correlated with the GFAP concentration in the patient plasma. The limit of detection (LOD) values of 20 fg/mL (400 aM) in buffer solution and 231 fg/mL (4 fM) in patient plasma have been achieved using this approach. In parallel, for the first time, we compare our results to the state-of-the-art single-molecule array (Simoa) technology and the classic enzyme-linked immunosorbent assay (ELISA) for reference. The GFET biosensor shows competitive LOD to Simoa (1.18 pg/mL) and faster sample-to-result time (<15 min), and it is also cheaper and more user-friendly. In comparison to ELISA, GFET offers advantages of total detection time, detection sensitivity, and simplicity.

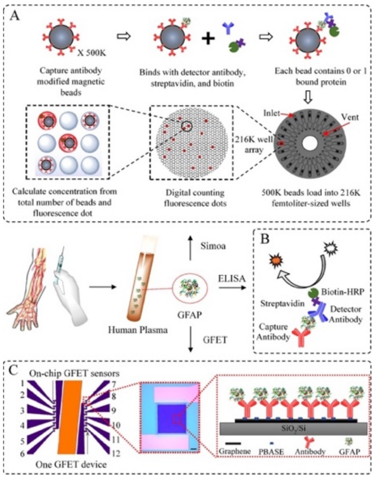


Figure 6: Schematic of the methods for GFAP detection. (A) State-of-the-art Simoa technology relies on the effective binding between 500 K antibody-modified magnetic beads and the GFAP molecules at a low concentration. (B) Classic sandwich ELISA uses an HRP-based colorimetric detection. (C) On-chip GFET biosensing platform uses anti-GFAP functionalized graphene channel as a sensing element.

The aim of the study was to develop a point-of-care diagnostic tool for the monitoring of traumatic brain injury in resource limited clinical settings, such as GP surgeries and patient homes. A proof-of-concept study showed that it is technically feasible to detect GFAP directly from patients' blood samples. Further optimisation of the sensing system to detect those important biomarkers with lower natural concentrations in blood and large-scale validation in more patients' samples is now required.

Glial Fibrillary Acidic Protein Detection

- A supersensitive tool for the direct detection of GFAP from TBI patients' blood.
- The biosensor shows competitive LOD to Simoa (1.18 pg/mL) and faster sample-to-result time with a faster detection time.
- A promising biosensor for monitoring of neurological diseases such as those from blast injury patients via blood biomarkers.

A review of through-knee amputation

Panhelleux B, Shalhoub J, Silverman A, McGregor AH. (2021)

Vascular (30)

Through-knee amputation (TKA) is an umbrella term for three different surgical techniques, each of which may affect clinical and functional outcomes for the patient. This work examines the frequency of through-knee amputations in England, looking at the concepts behind the surgical approach in order to stimulate further discussion and research on through-knee amputation and surgical outcomes. National Health Service statistics in England were used to examine the frequency of through-knee amputations over the past decade (2011 – 2020). It was found that 4.6% of major lower limb amputations were TKAs, however, it was not possible in all cases to determine the specific surgical technique used for these as they were not documented.

Through a systematic literature review, the influence of the different techniques on the clinical, functional, and biomechanical outcomes were examined. Unfortunately, it was not possible to clearly determine if the outcomes of TKA were preferable to above-knee amputations (AKA).

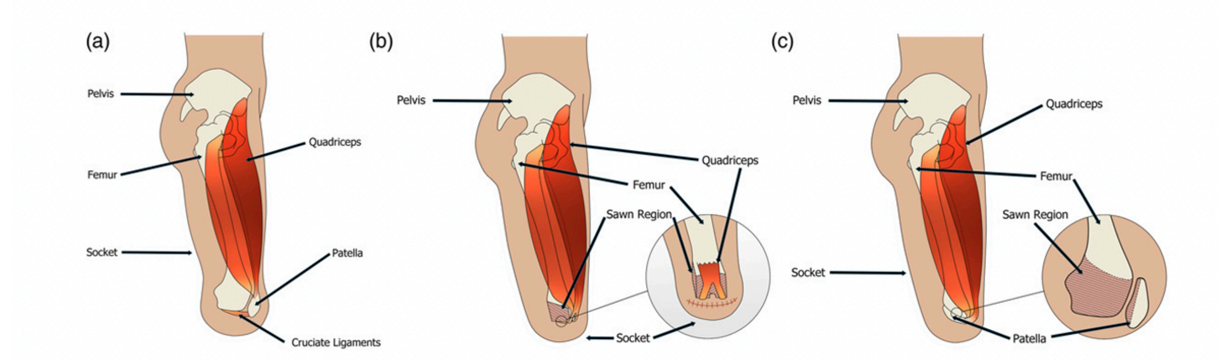


Figure 7: Schematic of the residual limb after through-knee amputation following different techniques. (a) Classical approach: the patella is preserved, and the patellar tendon is attached to the cruciate ligaments. (b) Mazet technique: the femoral condyles are shaved, the patella is removed and the quadriceps tendon is attached to the cruciate ligaments. (c) Gritti-Stokes technique: the femur is divided transversally, and the patella is attached at the distal cut end of the femur.

To address this uncertainty, TKA surgical techniques need to be thoroughly documented when presenting outcomes and in comparing TKA to AKA. This information is critical to guide future surgical decision making in major lower limb amputation and improve the subsequent design of sockets and prostheses, with a view to optimising outcomes.

A review of through-knee amputation

- 4.6% of major lower limb amputations were through-knee amputations.
- 3 distinct techniques for through-knee amputations are presented.
- It is still not clear if there is a preferable outcome to the patient with through-knee amputation over above-knee amputation.

Issues faced by people with amputation(s) during lower limb prosthetic rehabilitation: A thematic analysis.

Turner S, Belsi A, McGregor AH (2022)

Prosthetics and Orthotics International 46 (1) 61-67

Successful rehabilitation is essential to improve the physical and mental outcomes of people with lower limb amputation(s). Individuals have different goals and expectations of successful rehabilitation and experience issues that affect their quality of life. Through a thematic analysis of semi-structured interviews, the study aimed to determine factors affecting lower limb prosthetic rehabilitation from people with amputation(s). Ten people selected from an online survey, were interviewed on the telephone to explore the biggest impactors on and frustrations with rehabilitation and the socket. A thematic analysis of the answers was undertaken to determine five distinct, but inter-related themes as shown in Figure 8

This analysis aimed to portray first-hand experiences of individuals with amputation(s) through lower limb prosthetic rehabilitation, documenting major frustrations and impacts. The themes identified were all found to directly impact on the causes of frustrations and the impact these have on everyday life. In correlation with other studies, specifically one from the National Health Service (NHS), it appears that the experience of rehabilitation could be dependent on geographical location as well as by the provider of services (NHS, private or military). Although this is unclear and would require more specific analysis and questions to confirm.

The article acknowledges that the small sample size (n=10) and the recruitment strategy for the interviews could limit the study. However, the study provides a preliminary insight and a basis for further study.

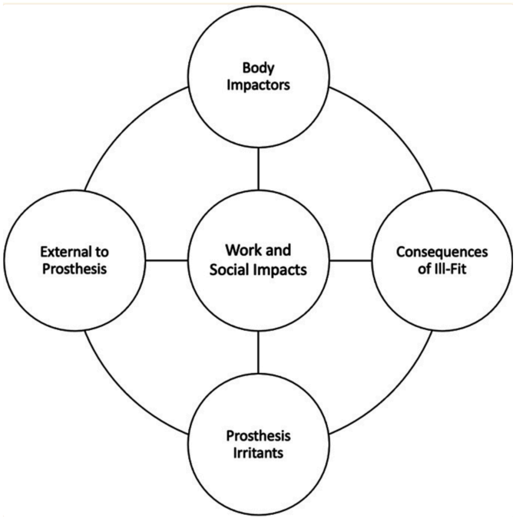


Figure 8: Themes identified in interview

Lower limb prosthetic rehabilitation issues

- Five distinct but inter-related themes were identified from the thematic analysis: *Body Impactors, External to Prosthesis, Consequences of Ill-Fit, Prosthesis Irritants and Work and Social Impacts*
- A basis for further research has been provided which could address frustrations, limit their impact, and improve quality of life.

Issues faced by prosthetists and physiotherapists during lower-limb prosthetic rehabilitation: A thematic analysis

Turner S, Belsi A, McGregor AH (2022)

Frontiers in Rehabilitation Sciences, section Rehabilitation for Musculoskeletal Conditions

Successful prosthetic rehabilitation is essential to improve the physical and mental outcomes of people with lower-limb amputation. Evaluation of prosthetic services from a prosthesis user perspective have been published and commissioned by the national bodies, however, the perspectives of clinicians working with service users during rehabilitation have not to date been sought. Throughout rehabilitation, patients interact with various clinicians, including occupational therapists and surgeons, amongst others. However, most of them will be with prosthetists, who prescribe the prosthesis, and physiotherapists, who guide strength training and movement re-education. Six clinician interviewees (2 prosthetists, 4 physiotherapists) were therefore, self-selected from a survey exploring issues and frustrations during lower-limb prosthetic rehabilitation. Semi-structured interviews explored the impactors on and frustrations with rehabilitation and the prosthetic socket. A thematic analysis was subsequently conducted to identify themes in the responses. Five themes were identified, which are shown in Figure 9, each of which though distinct, relates to the others either as a cause or consequence and should be viewed as such.

The article acknowledges that the small sample size (n=6) may not represent the overall clinical population, however it was able to provide formal documentation and an initial insight into the experiences of clinicians who work with people with lower-limb amputations through rehabilitation. It is unclear whether data saturation was achieved through the analysis and there may be additional themes that were not identified in the study.

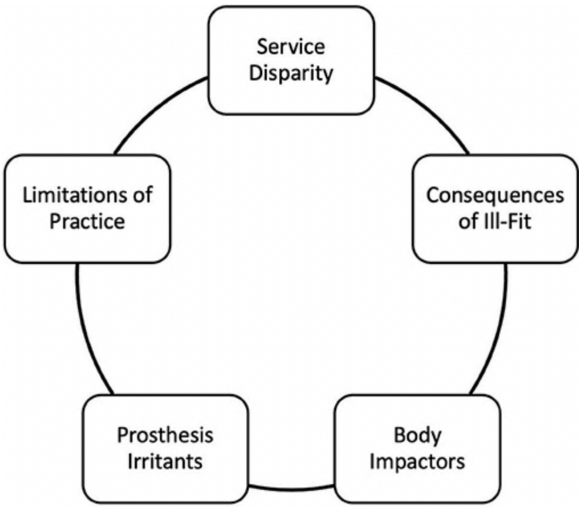


Figure 9: Themes identified from interviewee responses

Issues faced by Prosthetists and Physiotherapists

- Five distinct but inter-related themes were identified from the thematic analysis: *Body Impactors, Service Disparity, Consequences of Ill-Fit, Prosthesis Irritants and Limitations of Practice*
- The initial documentation provides a foundation for further research and improvements to policy and practice.

The impact of limited prosthetic socket documentation: a researcher perspective

Olsen J, Turner S, Chadwell A, Dickinson A, Ostler C, Armitage L, McGregor AH, Dupan S, Day S. (2022)

Frontiers Rehabilitation Science Front. Rehabilit. Sci.

The majority of limb prostheses are socket mounted. For these devices, the socket is essential for adequate prosthetic suspension, comfort, and control. The socket is unique among prosthetic components as it is not usually mass-produced and must instead be custom-made for individual residual limbs by a prosthetist. The article aims to highlight the issues caused by the lack of published information surrounding prosthetic socket manufacturing and evaluation—the key stages of prosthetic socket provision identified by the authors. The article takes the format of an opinion piece; a first-hand account from a group of seven biomedical engineering researchers and two clinician researchers (one physiotherapist and one prosthetist). It is hoped that formally documenting some of the key issues will raise questions to inform future research and evidence the requirements to obtain a clear definition of a well-fitting socket.

This article proposes there should be detailed published information regarding the elements of socket design and fabrication that are currently based upon implicit knowledge. It provides a call for a clear, universal definition of what constitutes a good socket fit and how it differs from comfort, based on an in depth understanding of clinician and user experience. Finally, it highlights the need for universally accepted outcome measures to evaluate the fit of a prosthetic socket and enhanced data sharing between clinics and researchers.

Impact of Limited Prosthetic Socket Documentation

- The prosthetic socket is custom-made for individual residual limbs by a prosthetist.
- There is limited information on the details of prosthetic manufacturing and evaluation.
- Socket design and fabrication elements should be published with a universal definition of a "good socket fit".
- Universally accepted outcome measure and improved data sharing is required.

Mapping lower-limb prosthesis load distributions using a low-cost pressure measurement system

Hopkins MO, Turner S, McGregor AH. (2022)

Frontiers in Medical Technology-Diagnostic and Therapeutic Devices, 17 (4), 908002

The prosthetic socket of people with major limb amputation is problematic for users in relation to comfort and acceptance of the prosthesis; and is associated with the development of cysts and sores. This paper aimed to determine the ability of a prototype low-cost system for assessing in-socket loading profiles of a person with an amputation during walking. The device was evaluated on four transtibial participants of various age and activity levels. Measurements were taken during level walking in a gait lab. The sensors were able to dynamically collect data, informing loading profiles within the socket which were in line with expected distributions for patellar-tendon-bearing and total-surface-bearing sockets.

The sensors provided objective data showing the pressure distributions inside the prosthetic socket. The sensors were able to measure the pressure in the socket with sufficient accuracy to distinguish pressure regions that matched expected loading patterns. The information may be useful to aid fitting of complex residual limbs and for those with reduced sensation in their residual limb, alongside the subjective feedback from prosthesis users.

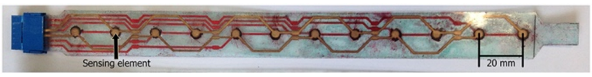


Figure 10: Low-cost, flexible pressure sensor strip containing 12 sensing elements

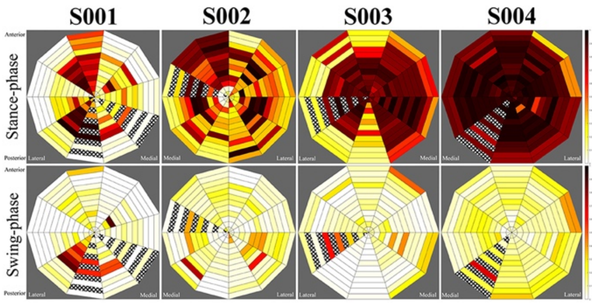


Figure 11: Average central step pressure maps for each subject. Top row: stance phase, bottom row: swing phase

Work is ongoing with prosthetists and physiotherapists to further develop the hardware and understand how they would like to use the information *via* appropriate visualisation methods.

Mapping load-distribution in lower-limb prostheses

- A prototype low-cost system has been developed combining low profile pressure sensitive sensors with an inertial measurement unit to assess loading distribution within prosthetic sockets.
- The sensor was able to provide objective data showing the pressure distributions within the prosthetic socket.
- The information could aid prosthetists and physiotherapists in fitting prostheses on patients.

Pattern of upper limb amputation associate with lower limb amputation: The UK military experience from Iraq and Afghanistan

McMenemy L, Mondini V, Roberts DC, Kedgley A, Clasper JC, Stapley SA (2022)

BMJ Military Health 169 (e1): e20-e23

The conflicts in Iraq and Afghanistan resulted in large number of personnel sustaining extremity injuries. In the context of polytrauma, partial hand amputation is often unrecorded. The aim of this work was to quantify the burden of upper limb (UL) amputation at any level occurring concurrently with a major (ankle and proximal) lower limb (LL) amputation. Knowledge of this cohort could aid in prosthetic modification to further improve quality of life outcomes in a population with dexterity loss.

A trauma database search was undertaken for all UK military LL amputees from the conflicts in Iraq and Afghanistan. A manual search method was employed to identify from the major LL amputees those who had a concurrent UL amputation at any level (including isolated finger amputation); Demographics, level of amputation, and injury profile data were recorded.

Sixty-eight individuals were identified; the most prevalent population was bilateral LL with a unilateral UL amputation (60%). Most UL amputations were partial hand (75%). There was no statistically significant difference between left or right side (p=0.13). On the left side, correlation was found between amputation of the thumb and third digit (rho – 0.34; p=0.005) but this was not seen on the right.

The rate of UL amputation at any level, in combination with LL amputation as a result of blast injury was determined. Knowledge of these combinations enables further research to support anecdotal evidence that there is a need for tailored prosthetics in the context of potential dexterity loss making donning and doffing problematic.

Upper limb amputation associated with lower limb amputation.

- A search was undertaken to quantify the burden of upper limb amputation concurrent with lower limb amputation and the rate was determined.
- Quantification of these combinations will support the need for tailored prosthetics for this cohort.

The critical role of a backing material in assessing the performance of soft ballistic protection

Nguyen T-T, Tsukada H, Breeze J, Masouros SD (2022)

Human Factors and Mechanical Engineering for Defense and Safety 6 (1), 13

Penetrating trauma by energised fragments is the most common injury from an explosive event. Fragment penetrations to the truncal region can result in lethal haemorrhage. Personal armour is used to mitigate ballistic threats; it comprises hard armour to protect from high-velocity bullets and soft armour to protect against energised fragments and other ballistic threats (such as from a handgun) with low impact velocities. Current testing standards for soft armour do not focus on realistic boundary conditions, and a backing material is not always recommended. This study provides a comprehensive set of evidence to support the inclusion of a backing used in testing of soft body armour. Experiments were performed with the CBIS gas-gun system using fragment-simulating projectiles (FSPs) of different shapes and sizes to impact on a woven aramid and a knitted high-performance polyethylene ballistic fabric, with and without the ballistic gelatine soft tissue simulant as the backing material.

The results showed statistically significant differences in the impact velocities at 50% risk (V_{50}) of fabric perforation across all test configurations when the gelatine backing was used (Figure 12). Furthermore, the backing material enabled the collection of injury-related metrics such as V_{50} of tissue-simulant penetrations as well as depth of penetration against impact velocity. The normalised energy absorbed by the fabric could also be calculated when the backing material was present.

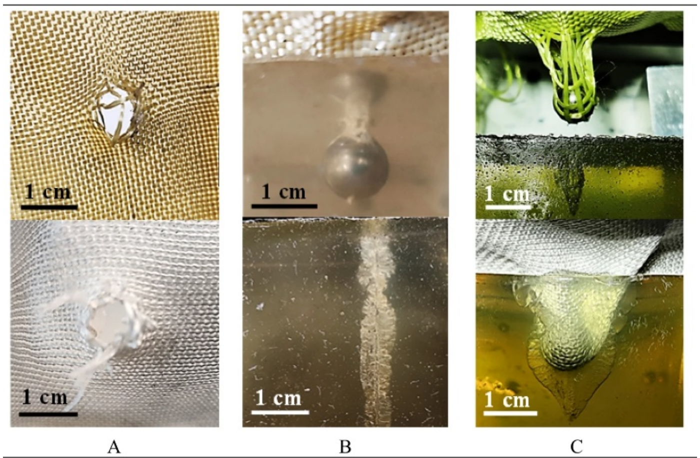


Figure 12: Exemplars of (A) material perforation, (B) gelatine penetration with material perforation where the FSP was retained in or went through the tissue simulant, and (C) gelatine penetration with no material perforation where the FSP was removed when pulling the fabric

This study confirms that a backing material is essential, particularly when assessing the performance of single layer fabrics against FSPs of low mass. It also demonstrates the additional benefits provided by the backing for predicting injury outcomes.

Having a relevant backing material is important when testing soft armour

- A backing material is essential when assessing ballistic fabrics (i.e., soft armour) against FSPs.
- Having a backing material when testing soft armour enables one to predict better probability of injury and so protective efficacy of the soft armour.

Neuroprotection by the noble gases argon and xenon as treatments for acquired brain injury: A preclinical systematic review and meta-analysis

Liang M, Ahmad F, Dickinson R (2022).

British Journal of Anaesthesia 129 (2), 200-218

The noble gases argon and xenon are potential novel neuroprotective treatments for acquired brain injuries. Xenon has already undergone early-stage clinical trials in the treatment of ischaemic brain injuries, with mixed results. Argon has yet to progress to clinical trials as a treatment for brain injury. The aim of the study was to synthesise the results of preclinical studies evaluating argon and xenon as neuroprotective therapies for brain injuries.

After a systematic review of the MEDLINE and Embase databases, a pairwise and stratified meta-analysis was carried out and heterogeneity was examined. A total of 32 studies were identified (14 for argon and 18 for xenon) involving measurements from 1384 animals, comprising of various brain injury mechanisms including traumatic brain injury often associated with blast injury. Both argon and xenon had significant (P<0.001), positive neuroprotective effect sizes.

These findings provide evidence to support the use of xenon and argon as neuroprotective treatments for acquired brain injuries. Current evidence suggests that xenon is more efficacious than argon overall.

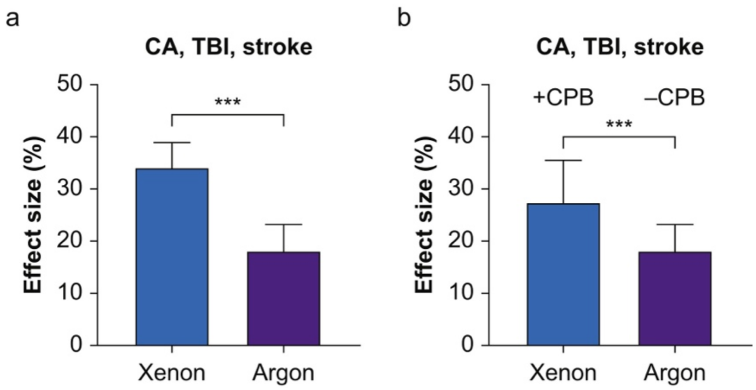


*Figure 13: Neuroprotective effects of xenon and argon. (a) Comparison of overall neuroprotective effects of xenon (blue bar) and argon (purple bar) including cardiac arrest (CA), traumatic brain injury (TBI) and stroke models for both gases. (b) Comparison of overall neuroprotective effects of xenon (blue bar) and argon (purple bar), including cardiopulmonary bypass (CPB) model in xenon group only. Bars represent the effect size (%) and error bars represent standard error (se); ***P<0.001, χ^2 test.*

The findings provide supporting evidence for the application of xenon and argon in clinical acquired brain injury therapy, and to guide the design of the future preclinical and clinical study protocols. Additional preclinical studies with both gases to address therapeutic time window and efficacy in female, older, and comorbid animals would be advantageous to facilitate clinical translation.

Neuroprotection by the noble gases argon and xenon

- Preclinical literature indicates that argon and xenon are neuroprotective. Xenon appears more effective than argon.
- The results encourage clinical trials of the use of xenon and argon in brain injury.

Protective clothing reduces lower limb injury severity against propelled sand debris in a laboratory setting

Rankin IA, Nguyen T-T, McMenemy L, Breeze J, Clasper JC, Masouros SD (2022)

Human Factors and Mechanical Engineering for Defense and Safety 6 (1), 12

The contribution of energised environmental debris to injury patterns of the blast casualty is not known. The extent to which personal protective equipment (PPE) limits the injuries sustained by energised environmental debris following an explosive event is also not known. In this study, a cadaveric model exposed to a gas-gun mediated sand blast was utilised which reproduced soft-tissue injuries representative of those seen clinically following blast.

Mean sand velocity across experiments was 506 ± 80 m/s. Cadaveric samples wearing standard-issue PPE were shown to have a reduced injury severity to sand blast compared to control: a statistically significant reduction was seen in the total surface area (143 mm^2 *vs*. 658 mm^2, $p = 0.004$) and depth of injuries (0 *vs*. 23 deep injuries, odds ratio = 0.0074, 95% confidence intervals 0.0004–0.1379) (Figure 14) (Figure 15).

Figure 14: Tier 1 pelvic personal protective equipment worn on cadaveric thigh; post-impact delivered to region of two-layer high-performance knitted silk protection

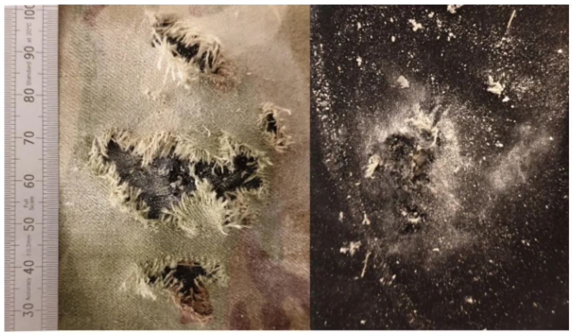


Figure 15: Exemplar damage sustained by standard-issue combat trousers (left) and PPE (right) following impact with sand debris

This study is the first to recreate wounds from propelled sand in a human cadaveric model. These findings implicate environmental debris, such as sand ejected from a blast event, as a critical mechanism of injury in the blast casualty. Tier 1 pelvic PPE was shown to reduce markedly the severity of injury. This injury mechanism should be a key focus of future research and mitigation strategies.

Protective clothing protects the pelvic region from propelled sand debris

- Standard issue tier 1 PPE significantly reduces injury severity from sand blast compared to no PPE worn.

Penetration of energized metal fragments to porcine thoracic tissues

Nguyen T-T, Breeze J, Masouros SD (2022)

Journal of Biomechanical Engineering 144 (7), 071002

Energized fragments from explosive devices have been the most common mechanism of injury to both military personnel and civilians in recent conflicts and terrorist attacks. Fragments that penetrate the thoracic cavity are strongly associated with death due to the inherent vulnerability of the underlying structures.

The aim of this study was to investigate the impact of fragment-simulating projectiles (FSPs) to tissues of the thorax in order to identify the thresholds of impact velocity for perforation through these tissues and the resultant residual velocity of the FSPs.

The CBIS gas-gun system was used to launch 0.78-g cylindrical and 1.13-g spherical FSPs at intact porcine thoracic tissues from different impact locations. The sternum and rib bones were the most resistant to perforation, followed by the scapula and intercostal muscle (Figure 16). For both FSPs, residual velocity following perforation was linearly proportional to impact velocity.

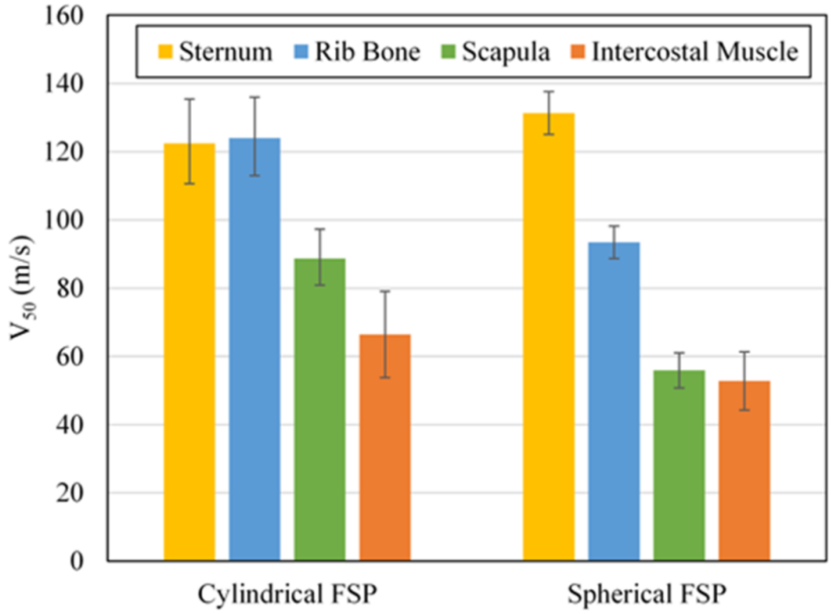


Figure 16: The impact velocity at 50% risk of perforation (V_{50}) through the thoracic tissues by 0.78 g cylindrical and 1.13 g spherical FSPs. The error bars denote 95% confidence intervals of the Weibull fitting or the standard deviation of the V_{50} values.

These findings can be used in the development of numerical tools for predicting the medical outcome of explosive events, which in turn can inform the design of public infrastructure, of personal protection, and of medical emergency response.

Penetration injury to thoracic tissues

- Sternum and rib bone are the most resistant thoracic tissues to perforation.
- The scapula and intercostal muscle (area in between ribs) were relatively weaker.
- These findings are useful for the more accurate prediction of severe injury to vital organs protected by the skeleton.

Stature and mitigation systems affect the risk of leg injury in vehicles attacked under the body by explosive devices

Rebelo EA, Grigoriadis G, Carpanen D, Bull AMJ, Masouros SD (2022)

Frontiers in Bioengineering and Biotechnology, 11

A finite-element (FE) model, previously validated for underbody blast (UBB) loading, was used here to study the effect of stature and of mitigation systems on injury risk to the leg. A range of potential UBB loadings was simulated. The risk of injury to the leg was calculated when no protection was present, when a combat boot (Meindl Desert Fox) was worn, and when a floor mat (IMPAXXTM), which can be laid on the floor of a vehicle, was added.

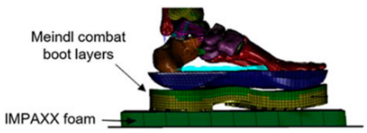


Figure 17: Close up of the computational model in the foot region showing the sole of the combat boot and blast mat.

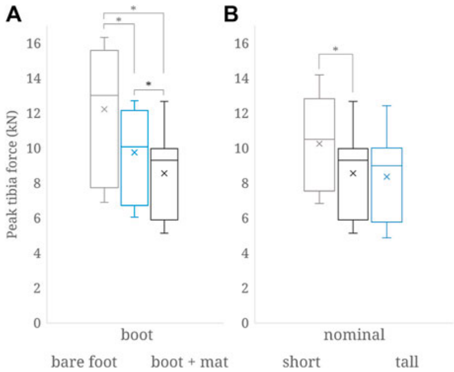


Figure 18: Comparison of peak tibia force distributions between (A) original, baseline model and mitigation represented by the combat boot and the combat boot and the IMPAXX floor mat; (B) short, tall, and the nominal stature all with a combat boot and the floor mat. Statistical significance (p < .05) using the Student's t-test between the distributions is noted with the asterisk.

The risk of injury calculated indicates that the floor mat provided a statistically significant reduction in the risk of a major calcaneal injury for peak impact speeds below 17.5 m/s when compared with the scenarios in which the floor mat was not present (Figure 18A). The risk of injury to the leg was also calculated for a shorter and a taller stature compared to that of the nominal, 50th percentile male anthropometry; shorter and taller statures were constructed by scaling the length of the tibia of the nominal stature. The results showed that there is a higher risk of leg injury associated with the short stature compared to the nominal and tall statures, whereas the leg-injury risk between nominal and tall statures was statistically similar (Figure 18B).

These findings provide evidence that the combat boot and the floor mat tested here have an attenuating effect, albeit limited to a range of possible UBB loads. The effect of stature on injury has implications on how vehicle design caters for all potential anthropometries and indeed gender, as women, on average, are shorter than men. The results from the computational simulations here complement laboratory and field experimental models of UBB, and so they contribute to the improvement of UBB safety technology and strategy.

Stature, boot, and floor mat affect injury risk in under-body blast

- Combat boot and floor mat offer protection in vehicle for a limited range of threats.
- A short stature is more likely to sustain severe foot injury in a vehicle attacked by a mine compared to an average or tall stature – implication on women in ground close combat who are on average shorter than their male counterparts.

Protective performance of helmets and goggles in mitigating brain biomechanical response to primary blast exposure

Yu X, Ghajar Mi. (2022)

Annals of Biomedical Engineering, Vol. 50 (Iss.11): pp 1579-1595

The current combat helmets are primarily designed to mitigate blunt impacts and ballistic loadings. Their protection against primary blast wave is not well studied. This paper comprehensively assessed the protective capabilities of the advanced combat helmet and goggles against blast waves with different intensity and directions.

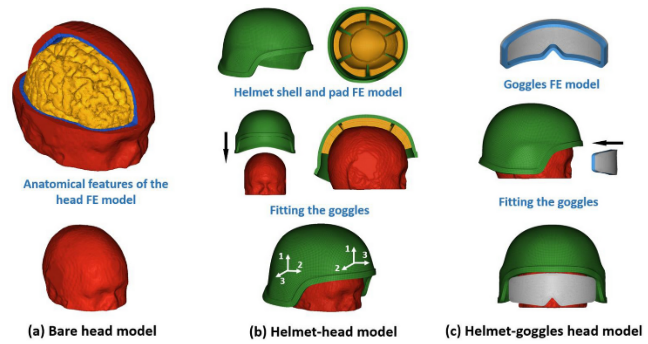


Figure 19: The computational model of the human head, goggle and helmet

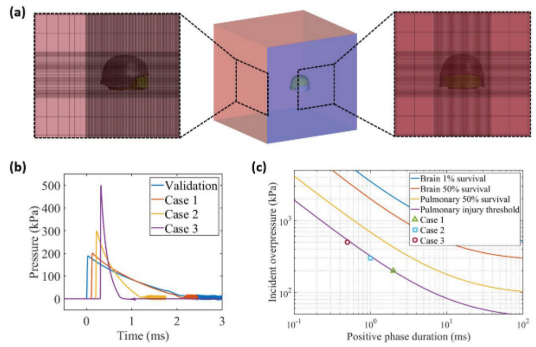


Figure 20: (a) The multi-size air mesh domain. (b) The blast wave loadings. (c) Brain/pulmonary injury criteria

The aim of the study was to investigate whether combat helmet and goggles could protect human head against blast wave exposure. The results show that helmet and goggles had minimal effects on mitigating cerebrospinal fluid (CSF) cavitation and even increased brain strain. Further investigation showed that wearing a helmet leads to higher risk of cavitation. In addition, their presence increased the head kinetic energy, leading to larger strains in the brain. These findings can improve understanding of the protective effects of helmets and goggles and guide the design of helmet pads to mitigate brain responses to blast.

Protective performance of helmets and goggles in primary blast exposure

- The protective performance of combat helmet and goggles in head protection under blast wave exposure was studied.
- Combat helmets can lead to higher risk of cerebrospinal fluid cavitation.
- Combat helmets and goggles had minimal effects on brain strain.

Non-lethal blasts can generate cavitation in cerebrospinal fluid while severe helmeted impacts cannot: A novel mechanism for blast brain injury

Yu X, Nguyen TT, Wu T and Ghajari M. (2022)

Frontiers in Bioengineering and Biotechnology, Vol. 10: 808113

Cerebrospinal fluid (CSF) cavitation is a likely physical mechanism for producing traumatic brain injury (TBI) under mechanical loading. This study investigated CSF cavitation under blasts and helmeted impacts which represented loadings in battlefield and road traffic/sports collisions.

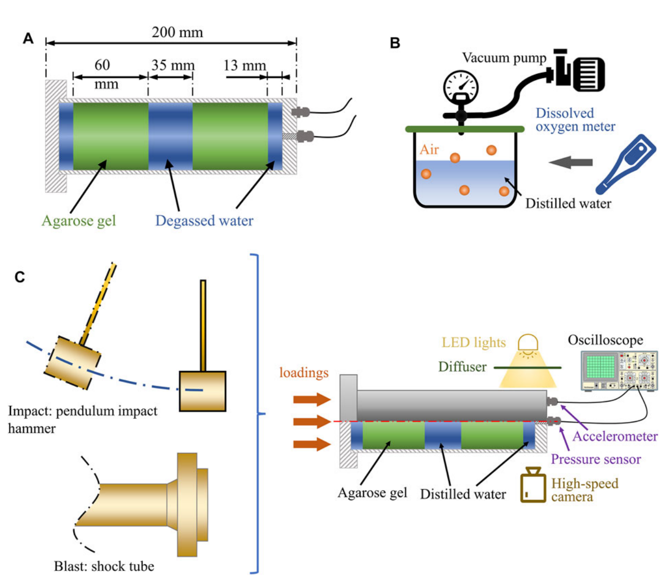


Figure 21: (A) The dimension of the 1D surrogate model. (B) The water degasification. (C) The set-up of the blast and impact tests.

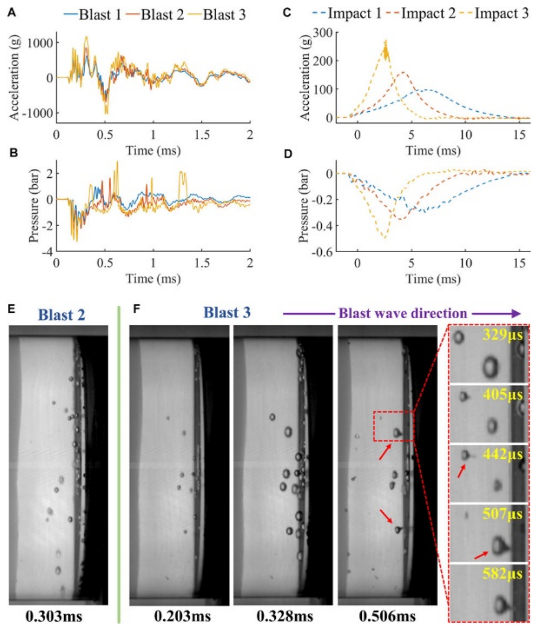


Figure 22: The acceleration and pressure histories of (A,B) blast tests and (C,D) impact tests. (E) The high-speed video footages of blast tests and the formation of micro-jets (red arrow).

The aim of the study was to investigate whether CSF cavitation can be induced under impact and blast loadings. First, the human head response under the blasts and impacts was predicted using computational modelling and it was found that the blasts can produce much lower negative pressure at the contrecoup CSF region than the impacts. Further analysis showed that the pressure waves transmitting through the skull and soft tissue are responsible for producing the negative pressure at the contrecoup region. Based on this mechanism, it was hypothesised that blast, and not impact, can produce CSF cavitation. To test this hypothesis, a one-dimensional simplified surrogate model of the head was developed and exposed to both blasts and impacts. The test results confirmed the hypothesis and computational modelling of the tests validated the proposed mechanism. These findings have important implications for prevention and diagnosis of blast TBI.

Generation of cavitation in cerebrospinal fluid

- It was found that CSF cavitation can be induced by blast loading, not helmeted impact loading.
- A mechanism to explain blast-induced CSF cavitation was developed, which is based on the pressure waves transmitted within the skull and soft tissues.

Investigation of blast-induced cerebrospinal fluid cavitation: insights from a simplified head surrogate

Yu X, Wu T, Nguyen T-T and Ghajari M. (2022)

International Journal Impact Engineering, Vol. 162: 104146

Blast induced traumatic brain injury (bTBI) has been a prevalent injury in recent conflicts. Post-mortem studies have shown damage in the brain tissue close to the cerebrospinal fluid (CSF) in bTBI cases. CSF cavitation is a potential mechanism for this brain/CSF interface injury. This study investigated the possibility and mechanism of blast induced CSF cavitation.

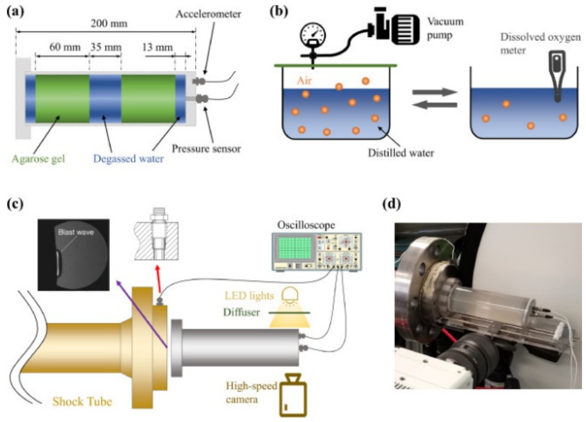


Figure 23: The dimension of the surrogate model. (b) The degasification and dissolved oxygen measurement of the distilled water. (c, d) The shock tube test setup

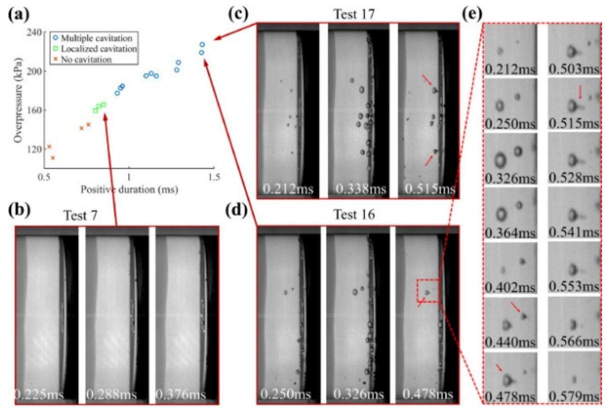


Figure 24: (a) Shock tube test results. (b-d) Localized and multiple cavitation video footage. (e) The micro-jets formation from the asymmetric collapse of cavitation bubbles.

The aim of this study was to explore the possibility and mechanism of blast induced CSF cavitation. First, a one-dimensional simplified human head surrogate was developed and exposed to nonlethal blast waves. High-speed videography and pressure sensors data showed the formation and collapse of cavitation in the CSF simulant. The mechanism of the cavitation using a finite element model of the head surrogate was explored. It was found that the pressure waves transmitting through the skull (outer wave) and tissue simulants (inner wave) are responsible for the generation and collapse of the cavitation bubbles, respectively. Next, this insight was used to explore the possibility of CSF cavitation in the human head using a detailed finite element model. The simulations verified the role of the inner and outer waves in the generation and collapse of cavitation. Finally, the CSF cavitation in head surrogate models with different lengths was studied. The results showed that the head length significantly affected the CSF cavitation, indicating the potential drawback of using small animals to study bTBI in human head. These findings can improve the understanding of the brain/CSF interface injury after blast exposure and inform the design of protection systems and animal tests.

Blast-Induced cerebrospinal fluid cavitation

- We found that the pressure waves transmitting through the skull and tissue simulants are responsible for the generation and collapse of the cavitation bubbles.
- We suggested potential drawback of using small animals to study bTBI in human head.

Appendix

Publications

Below is a list of publications that have arisen from the work within the Centre during 2022. Journal publications are important platforms for disseminating research findings.

Boos CJ, Schofield S, Cullinan P, Dyball D, Fear NT, Bull AMJ, Pernet D, Bennett AN (2022). *Association between Combat-Related Traumatic Injury and Cardiovascular Risk*. Heart 108, 367-374

Hazell GA, Pearce AP, Hepper AE, Bull AMJ (2022). *A critique of injury scoring systems when used for blast injuries: a narrative review with recommendations for future work.* British Journal of Anaesthesia 128, e127-e134

Dyball D, Bennett AN, Schofield S, Cullinan P, Boos CJ, Bull AMJ, Wessely S, Stevelink SAM, Fear NT (2022). *Mental health outcomes of male UK military personnel deployed to Afghanistan and the role of combat-injury: The ADVANCE cohort study*. Lancet Psychiatry 9, 547-554

Sargent W, Bull AMJ, Gibb I (2022). *Focused Assessment with Sonography in Trauma (FAST) performance in paediatric conflict injury.* Clinical Radiology 77, 529-534

Amiri P, Bull AMJ (2022). *Prediction of In Vivo Hip Contact Forces during Common Activities of Daily Living Using a Segment-Based Musculoskeletal Model.* Frontiers in Bioengineering and Biotechnology 10, 3389

Turner S, Belsi A, McGregor AH (2022). *Issues Faced by Prosthetists and Physiotherapists During Lower-Limb Prosthetic Rehabilitation* A Thematic Analysis Frontiers in Rehabilitation Sciences, section Rehabilitation for Musculoskeletal Conditions

Yu, X, Wu, T, Nguyen, TTN, and Ghajari, M, (2022). *Investigation of Blast-Induced Cerebrospinal Fluid Cavitation: Insights from A Simplified Head Surrogate.* International Journal of Impact Engineering, p.104146

Olsen J, Turner S, Chadwell A, Dickinson A, Ostler C, Armitage L, McGregor AH, Dupan S, Day S (2022). *The Impact of Limited Prosthetic Socket Documentation: A Researcher Perspective.* Frontiers in Rehabilitation Science

Hopkins MO, Turner S, McGregor AH (2022). *Mapping lower-limb prosthesis load distributions using a low-cost pressure measurement system.* Frontiers in Medical Technology-Diagnostic and Therapeutic Devices 17; 4:908002.

Liang M, Ahmad F, Dickinson R (2022). *Neuroprotection by the noble gases argon and xenon as treatments for acquired brain injury: a preclinical systematic review and meta-analysis.* British Journal of Anaesthesia, 129 (2), 200-218.

Yu X, Ghajari M (2022). *Protective Performance of Helmets and Goggles in Mitigating Brain Biomechanical Response to Primary Blast Exposure*. Annals of Biomedical Engineering 50, 1579-1595.

Yu X, Nguyen T-T, Wu T, Ghajari M (2022), *Non-Lethal Blasts can Generate Cavitation in Cerebrospinal Fluid While Severe Helmeted Impacts Cannot: A Novel Mechanism for Blast Brain Injury*. Frontiers in Bioengineering and Biotechnology

McMenemy L, Mondini V, Roberts DC, Kedgley A, Clasper JC, Stapley SA (2022) *Pattern of upper limb amputation associated with lower limb amputation: the UK military experience from Iraq and Afghanistan*. BMJ Military Health.

Panhelleux B, Shalhoub J, Silverman AK, McGregor AH (2022), *A review of through-knee amputation.* Vascular, 30 (6), Turner S, Belsi A, McGregor AH (2022). *Issues faced by people with amputation(s) during lower limb prosthetic rehabilitation: A thematic analysis* Prosthetics and Orthotics International, 46(1), 61-67.

Mallas EJ, Gorgoraptis N, Dautricourt S, Pertzov Y, Scott G, Sharp DJ (2022). *Pathological Slow-Wave Activity and Impaired Working Memory Binding in Post-Traumatic Amnesia.* Journal of Neuroscience, 42 (49), 9193-9210.

Azor AM, Sharp DJ, Jolly AE, Bourke NJ, Hellyer PJ (2022). *Automation and standardization of subject-specific region-of-interest segmentation for investigation of diffusion imaging in clinical populations.* PLOS ONE, 17(12) e0268233.

Xu L, Ramadan S, Akingbade OE, Zhang Y, Alodan S, Graham N, Zimmerman KA, Torres E, Heslegrave A, Petrov PK, Zetterberg H, Sharp DJ, Klein B, Li B (2022). *Detection of Glial Fibrillary Acidic Protein in Patient Plasma Using On-Chip Graphene Field-Effect Biosensors, in Comparison with ELISA and Single-Molecule Array* ACS Sensors, 7, 1, 253-262.

Nguyen, TTN, Tsukada, H, Breeze, J, Masouros, SD (2022) *The Critical Role of a Backing Material in Assessing the Performance of Soft Ballistic Protection.* Human Factors and Mechanical Engineering for Defense and Safety 6, 13

Rankin, IA, Nguyen, TTN, McMenemy, L, Breeze, J, Clasper, JC, Masouros, SD (2022). *Protective Clothing Reduces Lower Limb Injury Severity Against Propelled Sand Debris in a Laboratory Setting.* Human Factors and Mechanical Engineering for Defense and Safety 6, 12.

Nguyen TN, Breeze J, Masouros SD (2022). *Penetration of Energized Metal Fragments to Porcine Thoracic Tissues.* Journal of Biomechanical Engineering 1;144(7):071002.

Rebelo EA, Grigoriadis G, Carpanen D, Bull AMJ, Masouros S (2022). *Stature and mitigation systems affect the risk of leg injury in vehicles attacked under the body by explosive devices.* Frontiers in Bioengineering and Biotechnology 3;11:918013.

As well as the list of publications above, there are many other publications which are produced by Centre members. The above list has been kept to only those which are of direct relevance and funded by the Centre for Blast Injury Studies.

Books/book chapters

The 2nd edition of the Blast Injury Science and Engineering Book, published by Springer was released in 2022. There was a total of 47 chapters with five of these being section overviews. Of the 42 long chapters, 29 were authored by current or past CBIS members. Nine core academics contributed along with 23 past or current researchers. This edition was a significant update to the 1st edition and was the result of a great example of collaboration.

Public Engagement

Western Front Association membership talk: 11th January
Society of Apothecaries Annual History of Medicine talk: 6th April
Chelsea Festival Walks: Famous Bomb Blasts and their Consequences, 23/24th April, Saturday 24th September
ICRC Report into Effects of Urban Warfare launch: 27th January
Streatham Society talk: Stretcher Bearers of the Great War: 1st February
Society of Apothecaries Ethics event: Futility and Forensic Humanitarianism: 7th May
Royal College of Anaesthetists: Paediatric and Adult Blast Injury: 12th May
Attendance at All Parliamentary Committee on Explosive Weapons: 15th May
RMA: Conference on Role One care provided by Mil Med: 23rd May
THOR Conference, papers on point of care in blast injury and the history of haematology in trauma, 26th-29th June
The RAF Club: talk on the Guinea Pig Club, 7th October.
Wells Festival of Literature, talk with Harry Parker, 18th October
BSHPCH: paediatric and adult blast injury talk, 18th November

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