Imperial College London

THE ROYAL BRITISH LEGION

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CENTRE FOR BLAST INJURY STUDIES
AT IMPERIAL COLLEGE LONDON

2016

CBIS Annual Report

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

April 2017

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Centre for Blast Injury Studies Annual Report

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

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London, April 2017

Imperial College of Science, Technology and Medicine

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Director's Foreword

The report of the Iraq Inquiry was published in July of this year. In 2003, and for the first time since the Second World War, the United Kingdom took part in an invasion and full-scale occupation of a sovereign State with devastating consequences still visible today. Sir John Chilcot's inquiry highlighted the lesson that all aspects of any intervention need to be calculated, debated and challenged with the utmost rigour. Alongside colleagues at the King's Centre for Military Health Research (KCMHR) and the Institute of Psychiatry, Psychology and Neurosciences (IoPPN) at King's College London, I contributed to an editorial in the British Medical Journal in response to the report[1]. Our conclusion was simple: the true legacy of the conflict for individuals and wider society, both in the UK and Iraq, may not be evident for many years to come. Despite the innovation in pre-hospital care that existed and the progress that was made in improving personal protective equipment for troops, the long-term outcomes for the many "unexpected survivors" of the Iraq conflict remain unknown. The Centre for Blast Injury Studies is collaborating with KCMHR and military colleagues at Headley Court on ADVANCE, the Armed Services Trauma Rehabilitation Outcome Study, in order to assess the physical, social and psychological challenges faced by survivors. Learning the long-term cardiovascular-, musculoskeletal-, mental health- and psychosocial-related outcomes of battlefield injury will make a significant contribution to providing an improved sustained transition into civilian life and enable better long-term medical care for present and future British military casualties. Recent events have shown us all too clearly that there is an increasing incidence in terrorist activities that result in major trauma to civilians. Our work, whilst focused on serving personnel and veterans, must be translated for the benefit of these victims of premeditated violence.

Lessons are meaningless unless we learn from them. Education has always been a big part of the Centre's activity and this year was no different. Military staff in the Centre were involved in the delivery of LIVEX, a Defence Medical Services training exercise to ensure appropriate future preparedness of military medics; they helped deliver an amputations surgical skills course funded by UK charity Find A Better Way, which saw 13 surgeons from nine mine-affected countries learn about through knee amputation; they also assisted in the teaching of a variety of undergraduate medical school modules. It is imperative that we continue to translate our experiences and research findings to the clinical domain for the benefit of current and future blast-injured individuals.

This year saw great success in the award of three PhDs and the retention of those same students in the Centre as post-doctoral researchers. We welcomed a further six postdocs to the Centre, along with Dr Dan Stinner, a US military orthopaedic trauma surgeon who is working with us to leverage US and UK military medical databases in order to identify optimal treatment methods for combat-injured patients with extremity injuries. We expanded our PhD cohort with the addition of five new students to the areas of shock physics, rehabilitation, foot and ankle injury modelling, hearing loss diagnosis and helmet design. We hosted visits from Mark Lancaster, Parliamentary Under Secretary of State for Defence Personnel and Veterans, Lt Gen Mark Poffley OBE, Deputy Chief of Defence Staff (Military Capability), Maj Gen Martin Bricknell, Director Medical Policy and Operational Capability, and AVM Richard Broadbridge, Director Healthcare Delivery and Training—all of these key meetings reinforced our contribution to the promotion, protection and restoration of the health of service personnel in the UK. Outside the academic environment, we celebrated our Advisory Board Veteran's Representative, David Henson, who represented GB at the Rio Paralympics, bringing home a bronze medal for the 200m T42 race. Congratulations all on another successful year in the Centre. Finally, I would like to take this opportunity to welcome our new Advisory Board members and to congratulate Lord Boyce, Chair of the Advisory Board, on the award of Honorary Degree of Doctor of Science. The award, presented in November, recognises his outstanding contribution to the military covenant and the better understanding of injuries to, and compensation for, service personnel.

Professor Anthony M J Bull FREng

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

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[1] *http://www.bmj.com/content/354/bmj.i3842*

Invited Foreword

Immediately ahead our most recent Strategic Defence and Security Review (2015), I spoke in the House of Lords about the Role and Capabilities of the UK Armed Forces. There was then, and continues to be today, an aspiration for the UK to be a global force for good across a full range of activities. To meet that aspiration in a world that is increasingly dangerous, the Government rightly look to the Armed Forces as a key tool in their panoply of options. To fulfil their role in delivering the aspirations, the Armed Forces must have endurance, stability and capability while being of a quality that makes us a partner of choice when operating with allies. People are, of course, the critical component of all of those features and it follows that the training, protection and restoration of these people are the foundation upon which all else is built.

I assumed the role of Chairman of the Centre's Advisory Board in 2012. In that capacity, I experience first-hand the depth and breadth of research, education and outreach activities undertaken in the Centre. I have the privilege of leading a board of some of the country's most experienced, driven and prominent figures from the fields of defence, industry, health and academia. Together, we provide strategic guidance, independent advice and an ambassadorial function to the team at CBIS. Our membership is carefully considered so that our advice, guidance and promotion of the Centre's work are both appropriate and constructive. I would like to take this opportunity to welcome those members who have joined the Board this year—and to thank existing members for their valued service to date.

This year I was fortunate to be seated in the Royal Albert Hall alongside over 2,200 Imperial College students graduating from a range of science and engineering degree courses. In congratulating the students, the College's President, Professor Alice P. Gast, stated that now more than ever their education, talents and perspective were required for the many global challenges that face each and every one of us. Finding solutions, she said, requires people who are technically adept; people who can work across disciplinary boundaries; people who are trained to think rigorously and to question the status quo. The Royal British Legion Centre for Blast Injury Studies epitomises her beliefs.

The multidisciplinary nature of the research programmes at CBIS will, I believe, offer many solutions. The growing team, working together at the forefront of science, engineering and medicine, are best placed to provide knowledge and understanding to the complex problem of blast injuries. The Centre's collaborative nature—not just at home but also overseas—in the form of a London trauma bioengineering initiative, a developing world surgical network and the embedding of a US military medical researcher within its team, will serve only to strengthen its contribution to tackling the global problem of the legacy of conflict.

At a time when Defence budgets are being cut, Government aspirations are not met with matching resources and the major problems facing the world extend beyond national borders, demanding global cooperation and collaboration, Imperial College must be commended: its continued support of the Centre for Blast Injury Studies will ensure that the Centre's academics continue to improve the training, protection and restoration of the UK's military personnel. I urge each of you, reading this report, to continue your support of the Centre and may we together look forward to the UK continuing to be a global force for good.

Admiral of the Fleet the Lord Boyce KG GCB OBE DL, DSc (h.c.)

Chairman, Advisory Board, The Royal British Legion Centre for Blast Injury Studies

Introduction

This annual report represents the fifth in series. It introduces new staff, summarises the Centre's published work during 2016 and its current associated research activities. It presents two biographical pieces from current researchers in the Centre and an update on one of our alumni making a difference in another walk of life. This report also highlights other leading work from our collaborators in the areas of blast injury and rehabilitation while detailing our efforts in education and engagement during the year. We include, as always, a review of our media presence and outreach activities throughout 2016. Most importantly for the Centre, we must maintain the quality of our research as we go forward. As such, our key priorities for 2017 are to recruit and retain key staff, including key postdoctoral researchers and a new cohort of PhD students; we will continue to actively seek new collaborations with other leaders, nationally and internationally, in order to advance the field; and we will extend our translational activities for the benefit of serving military personnel, veterans, and their families.

Figure 1: A snapshot of highlights from 2016
Top – The Report of the Iraq Inquiry is released (June), Professor Anthony Bull and Imperial College Provost Professor James Stirling celebrate David Henson's Paralympic success (September). Middle – we publish a study comparing the care and outcomes of military and civilian injured (May) ahead of our annual Networking Event which focused on the rehabilitation and regeneration of the blast-injured (November). Bottom – Imperial College Provost and President Professor Alice P. Gast present Lord Boyce with an Honorary Degree of Doctor of Science (November) and we continue our efforts in the investigation of injuries caused by under vehicle explosions (February).

Staffing & Facilities

Researchers Joining CBIS in 2016

This year we welcomed five new post-doctoral research associates to the Centre. With a broad range of PhD experience they join the existing CBIS team to investigate blast-related consequences such as hearing loss, spinal injury, amputation and heterotopic ossification. They are joined by three of our recently graduated PhD students wishing to expand their research programmes in lower limb injuries, the mitigation of primary blast and finite element analysis of bone fracture. For the first time the Centre welcomed a US military orthopaedic surgeon to join the existing British military personnel in the Centre in order to identify optimal treatment of combat-injured patients with extremity injuries. With a growing research team, administrative duties increase as well, so we welcome Melanie Albright to the team.

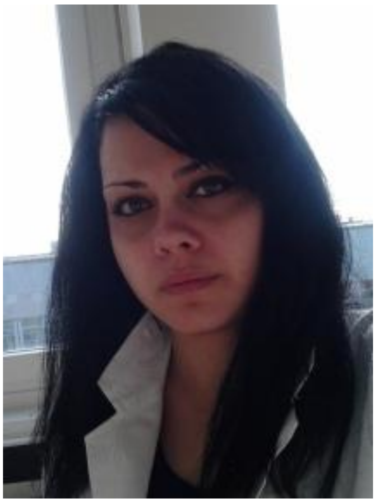
Dr Spencer Barnes joined the Centre as a post-doctoral research associate and is based in the Department of Mechanical Engineering under the supervision of Dr Jonathan Jeffers and Professor Anthony Bull. He was awarded a PhD from the University of Birmingham for research into the viscoelastic properties of the urinary bladder and surgical instrument design for the removal of bladder tumours. His current work in the Centre aims to develop an implant and the associated instrumentation for above-the-knee amputees.

Dr Michael Bruyns-Haylett's research background is in sensory neuroscience. Michael obtained a PhD from the University of Sheffield, where he investigated the relationship between neural activity and hemodynamics in the resting state. During his first postdoc (University of Reading) he examined the separate contributions of excitation and inhibition to neural population recordings. Michael is based in the Department of Bioengineering where he works as a post-doctoral research associate with Dr Andrei Kozlov in the Laboratory of Auditory Neuroscience and Biophysics. He is investigating the mechanisms of traumatic brain injury (TBI) in the auditory cortex, with a specific focus on how this impacts the balance between neural excitation and inhibition.

Dr Erica Di Federico joined the Centre as a post-doctoral research associate under the supervision of Professor Anthony Bull. She completed her PhD studies, which focused on the mechanoregulation of chondrocytes biosynthetic activity, at Queen Mary University of London. Erica's current research interests are on the structural organisation and tissue mechanics of the ligament to bone insertion site across strain rates, including blast. Findings of this study will provide information on the relationship between bone failure and ligament failure in traumatic amputation due to blast as well as support the development of computational models to analyse ligament failure and reconstruction, thus influencing mitigation for traumatic amputations.

Dr Nic Newell graduated with a MEng (Hons) degree in Mechanical Engineering from Durham University in 2009. He completed his PhD in the Department of Bioengineering at Imperial College London in 2013 wherein he investigated blast injuries to the foot and ankle and their mitigation. Nic played a pivotal role in the Centre as his PhD work enabled the development of much preliminary data prior to the official funding and establishment of the Centre. Following his PhD he undertook a two-year postdoc in Queensland University of Technology investigating the aetiology of adolescent scoliosis. We are thrilled that Nic has returned to the Centre as a post-doctoral research associate. His focus now is the examination of the biomechanics of spinal blast injuries under the supervision of Dr Spyros Masouros.

Daniel Stinner MD is a board-certified orthopaedic trauma surgeon in the US Army, currently assigned to CBIS as an exchange officer. He is currently working to leverage US and UK military medical databases to identify optimal treatment of combat-injured patients with extremity injuries. In addition, he is using his prior experience as the Medical Director of the Center for the Intrepid, San Antonio, Texas, to work with the team at CBIS to optimise outcomes of limb-salvage patients receiving a passive dynamic ankle-foot-orthosis. He continues to spend some of his time in San Antonio, where he is the director of the Skeletal Trauma Research Consortium (STReC) at the United States Army Institute of Surgical Research. He has published over 60 peer-reviewed publications, with more than 20 specifically evaluating outcomes and techniques associated with limb salvage and amputation. He is the Chairman of the Military Committee for the Orthopaedic Trauma Association and serves as faculty for the US Military's Combat Extremity Surgical Course and AAOS/ OTA/ SOMOS Disaster Response Course. In 2015, he was awarded the Surgeon General's Physician Recognition Award for a Major, which is awarded once a year to the top major out of over 1300 majors in the Army Medical Corps. As a result of these efforts, Dan was recently promoted to Associate Professor at the Uniformed Services University of the Health Sciences. He has been deployed to Afghanistan and has served on US Medical Readiness Training Exercises to Accra, Ghana, and Tegucigalpa, Honduras.



Dr Fani Tsitouroudi is a post-doctoral research associate in the Centre. She has a degree in Molecular Biology and Genetics (Democritus University of Thrace, Greece) and she completed her Master/PhD studies in Biochemistry in 2014 (Aristotle University of Thessaloniki, Greece). Her PhD work focused on *in vitro* osteogenesis and she obtained experience in the field of tissue engineering (bone). Before joining Imperial College, Fani worked as a post-doc at the Institute of Electronic Structure and Laser (IESL) of the Foundation for Research and Technology (FORTH) in Crete, Greece. Her studies focused on protein engineering for applications in the field of Biomaterials. Her current work is focused on the development of an *in vivo* model of heterotopic ossification (HO) related to blast injury under the supervision of Professor Anthony Bull. Because of her experience, Fani will contribute significantly to other *in vivo* studies in the Centre.

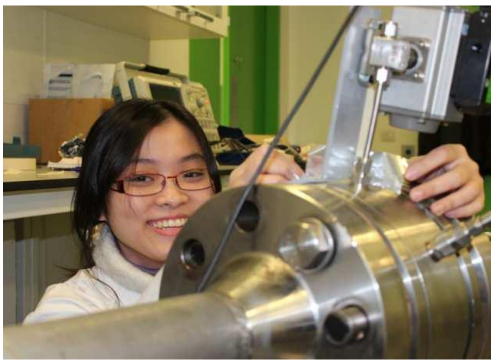
Administrative Support

Melanie Albright's time is shared between the Department of Bioengineering as research administrator and the Centre as its administrator. Along with providing research- and finance-related assistance to the Centre Manager, Melanie supports a range of activities, from recruitment and personnel administration to servicing governance meetings and coordinating seminars, conferences and large-scale events. The latter includes leading on the planning and delivery of the Centre's Imperial Festival involvement and Annual Networking Event, both of which in 2016 were bigger than ever before. Maintaining the Centre's online presence, creating its biannual newsletter and developing its brand through several media, Melanie enables the promotion of the Centre's work in clear and engaging ways and in line with its aims and strategic objectives. Before moving into research and finance support, Melanie's roles in Bioengineering included Departmental Secretary and Postgraduate Research Student Administrator, giving her a strong background to facilitate the Centre's initiatives, including increasing PhD numbers, strengthening collaboration among the team and overall process improvement.

From PhD to Post-doc

The Centre is committed to the career development of its individuals. We encourage high-quality PhD graduates, suited to a career in research or academia, to continue their careers in the Centre where their research area remains aligned with Centre goals. Whilst in the Centre they can expand their research, gain teaching experience and develop as independent experts in blast injury science and engineering in a supportive environment. This year we welcomed three of our former PhD students into post-doctoral research associate roles.

Dr Grigoris Grigoriadis completed his CBIS-funded PhD this year. Having studied heel biomechanics under blast conditions for over three years under the supervision of Dr Spyros Masouros and Professor Anthony Bull, Grigoris was well placed to undertake a study on the response of the lower limb in under-body blast and the effect of the posture on the injurious outcome under the supervision of Dr Masouros. After graduating, he participated for six months in a project funded by UK charity Find A Better Way aimed at developing functional and sustainable prosthesis for knee disarticulation amputees in landmine-affected countries. Before joining the Centre, he graduated from the Department of Mechanical Engineering at Aristotle University of Thessaloniki in Greece. His final year thesis included the ergonomics analysis of the driving posture in the cockpit of a racing car as a member of the Aristotle Racing Team, leading him to apply for the MSc course in Biomedical Engineering at Imperial College London, from which he graduated in 2012.



Dr Thuy-Tien (Luz) Nguyen began her post-doctoral research associate position under the supervision of Dr William Proud and Dr Spyros Masouros as a continuation from her PhD programme within the Centre. Luz was awarded her PhD in 2016 for her work on the characterisation of a shock tube system for the study and mitigation of primary blast injuries. The shock tube is a key piece of equipment in the Centre. Able to generate a welldefined pressure output of varying intensity and duration, it is a tool used in many studies to further the understanding of the interaction of shock waves and materials. Her current role involves developing a gas gun platform and the testing mechanism to study the penetration injuries by fragments to the human long bones. Results of the study can be used to determine the injury risk curve that can aid in injury mitigation.

Dr Claire Villette completed her PhD in CBIS under the supervision of Dr Andrew Phillips. She investigated structural meso- and miscroscale finite element methods for the prediction of bone failure. For this work, Claire was awarded a Doctoral Prize Fellowship from EPSRC. She is currently building on her PhD work with Andrew in the Department of Civil and Environmental Engineering. The main objective of her post-doctoral work is to implement and evaluate a digital tool for parametric optimisation of printable scaffold designs for Bone Tissue Engineering, accounting for heterogeneous mechanical properties and porosity. It is expected that in addition to increasing bone repair performance compared to existing designs, this tool will simplify and encourage the use of optimal designs in practice by relieving the end-user of the computational modelling burden.

Appointments

Surg Cdr Mansoor Khan (involved in our *Trauma Bioengineering Network*) was appointed Senior Lecturer in Military Surgery in the Academic Department of Military Medicine at the Royal Centre for Defence Medicine. In this role Mansoor supports the Defence Professor in the supervision of higher degree students conducting studies into the prevention and optimal management of illness and disease in the operational environment.

Dr Spyros Masouros was elected to the International Research Council on Biomechanics of Injury. As a member, Spyros will join others from around the world to deliver scientific conferences and training courses in order to provide an academically rigorous forum for the dissemination of the latest research into injury causation and protective systems. Spyros was also invited to join the NATO Human Factors and Medicine (HFM-271) Task Group, an international committee examining the existing and emerging data on occupant response and injury criteria from biomechanics research with military focus. The task group provides understanding of the effects of human body posture and protective equipment on injury severity and evaluates the applicability of current injury criteria. It also examines the use of anthropomorphic test devices (ATDs) and human models as suitable tools for injury assessment.

Awards

Admiral of the Fleet the Lord Michael Boyce received an Honorary Degree of Doctor of Science for his *outstanding contribution to the military covenant and the better understanding of injuries to, and compensation for, service personnel.* Imperial College London, UK. November 2016.

Professor Anthony Bull was inducted into the American Institute for Medical and Biological Engineering (AIMBE) College of Fellows for his *outstanding contributions to the basic mechanics of joints and tissues, and the study of military blast injuries*. Washington DC, USA. April 2016.

Barnett-Vanes A. Foulkes Fellowship for Academic Clinicians in Training. London, UK. January 2016.

Edwards DS. Philip Fulford Prize for Best Research Paper. *The Biomechanics of Blast Related Amputee Heterotopic Ossification: computation modelling and physical experiments.* Combined Services Orthopaedic Society (CSOS) Annual Conference. Plymouth, UK. May 2016.

Edwards DS. Gauvin Orthopaedic Society's Best Scientific Presentation Prize. *A meta-analysis of the Injury profile from Terrorist Bombings.* Wessex, UK. June 2016.

Rankin SM, Collaboration Award for Societal Engagement. *National Heart and Lung Repair Shop and Convenience Store: Science pop-up shops.* Imperial College London, UK. November 2016

Sharrock A. Richard Wiseman Medal for best presentation. *Blast trauma increases microvesicle shedding in an in-vivo model of thoracic blast trauma.* Association of Trauma & Military Medicine Conference. Belfast, Northern Ireland. May 2016.

Facilities

Shock tube

The shock tube is a versatile system that can generate controlled blast waves of specified loading conditions in the laboratory environment (Figure 2). Since 2013, it has been employed extensively to investigate the blast injury to lungs, respiratory and brain tissue; the response of various cell colonies; and the blast mitigation effect of a range of materials. A recent development of the shock tube includes an anvil system in the sample mounting. The adaptation creates not only the primary blast effect but also induces bone fracture in a desired location of the target limb. This will be used in an *in vivo* study of heterotopic ossification and the effect of various treatments on promoting this process.

Gas gun

The last few months have seen the development of a compressed-air-driven 32-mm-bore gas gun system (Figure 2). In this platform, a sabot carrying the desired projectile is accelerated along the 3m barrel to reach velocities between 20 and 500ms^{-1}. Upon exiting, a sabot stripper construction is used to ensure only the projectile impacts on the target of interest. Laser light gates are used to measure the impact velocity of the projectile. An enclosed target chamber with suitable windows is used for safety containment, whilst still enabling high-speed photography observation of the interested events. The immediate question to be addressed by this system is to identify injury thresholds of the long bones in secondary blast injuries due to the penetration of fragments.

Figure 2: CBIS researchers (foreground) Thuy-Tien Nguyen working with the new compressed-air-driven gas gun system and (background) Hari Arora working with the existing shock tube.

Governance

CBIS is afforded independent and external advice, strategic oversight and vigilant monitoring through its Advisory Board. Last year we reported additions to the function of the advisory board which were recommended during the review of the Centre in 2015. Strategic and financial plans are now reviewed by the board biannually in line with the set clinical priorities against perceived benefit to the intended beneficiary.

This year we are pleased to announce the expansion of our Advisory Board with the addition of four new members. We welcome Kate Davies OBE, Director of Commissioning for NHS England: Armed Forces & their Families; Lt Gen Louis Lillywhite CB, MBE, QHS, Retired Surgeon General; Sir Keith O' Nions FRS Hon.FREng, Former Chief Scientific Advisor, Ministry of Defence; and Professor Keith Willett CBE, National Clinical Director for Trauma Care, Department of Health.

These individuals join General Sir Tim Granville Chapman GBE KCB, ex-Vice Chief of the Defence Staff & Programme Director Defence and National Rehabilitation Centre, David Henson MBE, veteran's representative, Professor Sir Anthony Newman Taylor CBE, Chairman of the Independent Medical Expert Group of the Armed Forces Compensation Scheme and Ian Stopps CBE, former Chairman of Raytheon UK (retd. 2016), forming an executive oversight committee that enables the Centre to take its discoveries from the laboratory to the military frontline, in terms of protection and healthcare, and in order to improve outcomes for all injured personnel.

In addition to the strategic and financial reporting provided to the advisory board, the Centre reports biannually to its main funder, The Royal British Legion. This includes details of the progress of each research project, the recruitment of post-doctoral researchers and PhD students, a financial summary including any grant applications for external funding and an update on the Centre's collaborations; industrial or academic. The Ministry of Defence is, of course, a key stakeholder of the Centre and is engaged through regular meetings with Defence Professors. Senior military staff are hosted for briefings, and subject specific seminars are convened in relevant thematic areas. The Faculty of Engineering Research Committee at Imperial College reviews its research centres every two years to ensure certain criteria is satisfied for their continued recognition. In doing so the College is provided with a comprehensive report of the CBIS mission, its membership and partnerships, its successes to date, future plans and financial state, as well as its publications and output.

Due Diligence

On behalf of the Royal British Legion, an external review was conducted this year to assess independently the outputs of the Centre. The focal point of the review was a site visit in June, during which time an international and wholly independent panel of experts were convened to consider the Centre's progress to date and future plans.

The review was chaired by **Professor Hamish Simpson**, Professor of Orthopaedics and Trauma, and Consultant Orthopaedic Surgeon in the Department of Orthopaedic Surgery at the University of Edinburgh. Hamish specialises in limb reconstruction and is one of three individuals from the UK to be awarded an honorary fellowship of the Confederation of International Orthopaedic Research Societies. Hamish is also current President of the Combined Services Orthopaedic Society. The panel included **Professor Jane Burridge**, Professor of Restorative Neuroscience at the University of Southampton; **Professor Janet Lord**, Professor of Immune Cell Biology and Director of the Institute for Inflammation and Ageing at Birmingham University Medical School; **PD Dr Kai Uwe Schmitt**, Lecturer in Trauma Biomechanics, Institute for Biomedical Engineering, ETH Zurich; **Professor John Simpson**, Dean of Research and Clinical Innovation and Professor of Respiratory Medicine at Newcastle University; **Professor Peter Lim** is a Senior Consultant in Rehabilitation Medicine at the Singapore General Hospital and Clinical Professor, Physical Medicine and Rehabilitation with Baylor College of Medicine USA and; **Dr Michael Stone**, Senior Research Fellow in Audiology and Hearing Sciences at the University of Manchester. The review panel made a number of key points and eleven recommendations. These are summarised below.

Summary of key points: the Centre has established an important niche and international profile in the study of blast injury; the Centre has strong leadership including key military involvement; the Royal British Legion is commended for its support and commitment; and the institutional environment is a strength of the Centre.

Recommendations were made in the areas of: budget and future funding strategy (including applying for doctoral training centre funding in the near future); overall strategy (to further develop the head and lung injury strategy); translation and commercialisation (to further develop links with translational partners to optimise the development, protection and application of intellectual property developed at the CBIS); project prioritisation; mentoring of junior academic staff; publication strategy (higher impact and open access); and governance and scientific advice (to provide flexibility, initiate new projects and close other projects). The panel also reiterated the strength of the Centre's focus on military and veterans, and recommended that this focus be maintained.

The review panel agreed that a research infrastructure of the highest quality has been established and built up within CBIS, and that strong progress has been made to date. It commended the research team on the tremendous impact of certain studies; generating improvements to the surgical management and compensation of injury, and the translation of research findings to combat situations in the design and improvement of personal protective equipment. We are grateful to these experts for their invaluable advice and support.

Being a Researcher in CBIS

Dr Dilen Carpanen (Year 3 Post-Doctoral Research Associate)

My career has not been an intentional one by any means. Having studied science at high school, my career path was set to be in the engineering field since I had no intention of being a medical student for the fear of working with cadavers. The irony is that five years after my undergraduate in mechatronics engineering, I embarked on a PhD in biomechanics and subsequently a postdoc with CBIS that entailed substantial cadaveric work. Rest assure I can handle it now; most of the time.

Since my first day with CBIS, there is no such day which I can brand as “typical”. I sometimes have a plan, but rarely stick to it as much of my work is responsive to the needs of PhD students and other postdocs in the Centre. This promotes beneficial collaboration within the group and makes the daily routine more interesting. The range of things I can get involved in is huge and includes designing/modifying bespoke equipment for experiments, carrying out blast related experiments and creating computational models for students.

A recent challenge has been designing and developing a drop tower to enable the dynamic testing of materials at a range of impact velocities. One example it was used for was to determine the level of forces required to fracture the small joints of the hand in order to design and manufacture more efficient protective gloves for the army (Page 43). The equipment is also being used for many other experiments to understand the fracture mechanism of the pelvis and spine at high strain rate. In addition, I redesigned the by now well-known AnUBIS rig, which replicates the response of a vehicle floor pan that has been hit with an explosive blast so that higher impact severity can be simulated. This will help us to understand the effect of posture of mounted personnel in the field.

As far as computational modelling (mainly finite element analysis) is concerned, most of my time is spent creating the geometry and mesh of the desired tissues (lower limb, pelvis, and spine among others) from medical imaging scans of cadaveric specimens. The process for each structure can take at least two weeks depending on the complexity of the structures. The initial models are then passed over to the students for running blast loading scenarios mimicking our own experiments or other published material. In addition, one of my ongoing projects is modelling the optimum blast mat that will protect vehicle occupants. The aim is for the blast mat to absorb the load during a blast event and minimise the force transferred to the lower limb of the occupants.

Organising group meetings, preparing and delivering presentations, writing/reviewing scientific papers and hosting external visitors also forms part of my role to make sure that our research work is disseminated to the scientific community as well as to the general public. I was lucky enough to join CBIS straight after my PhD and working with people in the group has been inspiring career-wise. Their attitude and problem-solving nature has rubbed off on me. There are always some new interesting challenges involved in the job which I am ready to take on.

Sqn Ldr Claire Webster (Year 3 PhD Student)

I am a vascular and trauma surgeon in the Royal Air Force. I am taking some time out of training to undertake full time research, and I am currently a final year student at the Centre for Blast Injury Studies. My project is regarding the blast pelvis. Explosive injuries to the lower extremity were common in the recent conflicts in Iraq and Afghanistan, and indeed throughout the world in the civilian context. Effects from explosive devices can extend proximally towards the torso to involve pelvic and abdominal regions.

Prior to the commencement of this project, it was known that pelvic injury carried a high fatality in war-wounded personnel. However, specific fracture pattern detail, and a focus for improvement strategies was not yet in place. The initial clinical data analysis of my project revealed the following important clinical information regarding pelvic fracture due to explosives:

- pelvic fracture is the most important predictor of fatality in lower extremity injury;
- traumatic amputation of the lower limb and pelvic fractures occur together, meaning a linked mechanism is likely;
- there are different injury patterns to the pelvis in those standing versus seated at the time of injury, with patients standing sustaining fatal pelvic fractures;
- fatal pelvic fractures are secondary to the 'open pelvis' with disruption at the symphysis pubis and sacroiliac joints;
- these open pelvic fracture patterns have a high incidence of vascular injury;
- all fatalities in the blast pelvis were due to bleeding;
- in order to prevent further fatalities, only prevention of injury will have a significant effect on survival, as those who die from their injuries die before treatment can occur; and
- therefore, directing improvement strategies on body armour for the dismounted soldier will have the most profound effect on surviving pelvic fracture from explosives.

Analysis of the clinical data in this project was key, as this provided the clinical focus to ensure the research direction had a strong impact on current issues. Collecting this data alone required collaboration with the Royal College of Defence Medicine (RCDM), Centre for Defence Radiology, Defence Science and Technology Laboratories (DSTL), and subject matter experts; other clinicians like radiologists and orthopaedic surgeons, engineers experts in biomechanics of injury and fracture, and engineers and physicists familiar with explosive effects on vehicles and the human body.

Once the fracture pattern common to fatalities was realised, experimental strategies were then developed to reproduce these injuries in two different formats:

1) Cadaveric Studies.

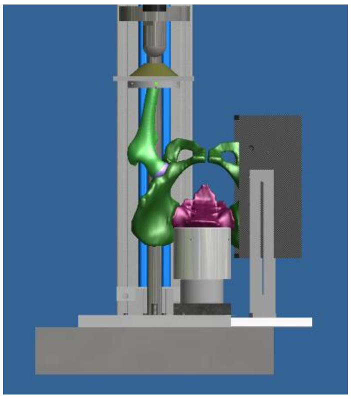
These experiments were aimed at physically fracturing the pelvis in a way that is realistic in explosive injuries. This gives key information as to the tolerance of the human pelvis to high rate loading as seen in blast, and injury thresholds. Experimental planning involved discussion and planning with engineers and clinicians to create new methods of testing the pelvis, not yet seen in the current literature. This is a complex process and required teamwork, cross specialty knowledge pooling, and problem solving.

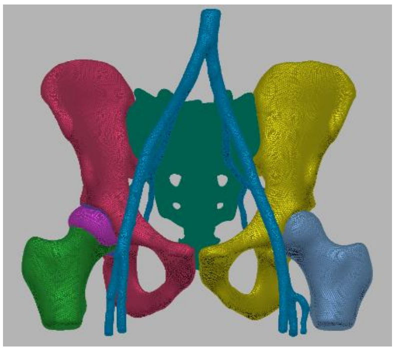
2) Finite Element Modelling

Finite element modelling is another method used to test the response of body tissues to particular stresses and strains using mathematical models to predict injury. The advantage of this method in this research, is that the model can test multiple conditions. This can therefore guide physical experiments, or provide new information as to loading patterns which cause fracture in the way we see them on the battlefield. In the pelvic model we included the main blood vessels within the pelvis in order to test vessel response on joint disruption, as blood vessel disruption is a key factor in fatality in pelvic fracture.

With a combination of the analysis of clinical data and developing appropriate testing strategies, this project will be able to contribute directly to injury prevention by providing evidence based recommendations to the Defence Equipment and Procurement Group, who have the ultimate responsibility to provide protective equipment for those likely to be exposed to blast. This project is likely to contribute directly to increasing survival from lower extremity injury on the battlefield.

Undergoing this research has continued the collaboration between multiple organisations: military and civilian medical expert groups both in the UK and further afield, experts in bio and mechanical engineering, defence procurement, and support from the Royal British Legion, and government. This work has been presented in engineering, medical and parliamentary groups both nationally and internationally. The high calibre of personnel, equipment, and funding and support available at Imperial College, has enabled projects such as these to fulfil their full research potential and have the maximum impact to defence, and contributing to the wider knowledge of traumatic injury.


(a)


(b)


(c)

Figure 3: (a): Experimental Set up for cadaveric pelvic experiments to induce pelvic shear using a drop tower technique. This applies loading via the femur to shear the unilateral hemipelvis. (b) Finite Element Model for the pelvis including major arterial tree. (c) Current personnel protective equipment in pelvic region injury for which modification to ensure efficacy is anticipated.

Alumni

Dr Ashton Barnett Vanes

Ashton was an inaugural 2012 PhD candidate at the Centre, and successfully completed his studies in 2015 under the supervision of Professor Sara Rankin. During his time at the Centre, Ashton contributed significantly to our understanding of primary blast injury by establishing and characterising the acute cellular inflammatory response. His studies revealed a robust and selective response of classical monocytes, in addition to neutrophils in blood and lung tissue following primary blast lung injury. This profile of immune cells in the blood could present a valuable clinical research tool in the monitoring and assessment of the immune response in blast injured patients.

Ashton's research led to the publication of two first author papers in *PLOS One* (Page 31) and *The Journal of Trauma and Acute Care* Surgery (Page 32) and with his findings also contributing to a study published in *Injury* (Page 33). From his work, and the skills gained during his PhD, Ashton was successful in attaining a Foulkes Fellowship. The Foulkes Foundation is a charitable foundation committed to promoting medical research, the training of scientists and the study of medicine. Ashton is the Editor of two books both to be published in 2017 – the first on 'How to Complete a PhD in the Medical and Clinical Sciences' by Wiley-Blackwell. Ashton has now returned to continue his medical training at St George's Hospital Medical School, after which time he plans to pursue an academic clinical career.

Education

It is imperative that lessons learned in the Centre's experiences and research activities are translated appropriately. Below we identify some of the conduits to achieving that goal.

LIVEX

The end of military operations does not signify a quiet time: pace is maintained with the peacetime training of Regular and Reservist Defence personnel. Across Defence Medical Services, trauma teams need to ensure appropriate future preparedness. A new model of pre-deployment training (LIVEX) was developed in 2015, bringing the placement of military trauma teams into civilian trauma centres. Two London NHS Major Trauma Centres, the Royal London Hospital and St. Mary's Hospital were chosen to host the initiative. Sqn Ldr Phill Pearce, current CBIS researcher and former Surgical Registrar at the Royal London, returned to facilitate the exercise this year. Military clinicians including surgeons, anaesthetists, emergency physicians, nurses, and radiographers from across the UK military were selected to participate. The training package included lectures, workshops and trauma simulation with the military team embedding into, and eventually taking over, all aspects of acute trauma care under the direction of local staff. The exercise has been run three times within this development period. In addition to refreshing trauma skills, emphasis was placed upon team interaction and the integration of civilian and military trauma systems.

Surgical Training

With support from UK charity *Find a Better Way*, and *Smith & Nephew* the inaugural *Surgical Training Course* took place in July 2016, employing literature, academics and current research streams from the Centre to develop and deliver bespoke training. Here, trauma surgeons from 10 different countries around the world applied the most advanced surgical methods to their clinical practice. After the course, the surgeons who attended became part of the Surgical Training Network, along with their trainers, to ensure continued communication, knowledge development and impact. The Surgical Training Course is the ideal vehicle to transfer lessons learned in military conflict to the civilian domain. Furthermore, it provides an opportunity to deliver measurable benefit to patients and the public in landmine afflicted countries and across the Developing World.

Figure 4: Surgical Training Course leader Professor Jon (Col) Clasper with the inaugural cohort; trauma and orthopaedic surgeons living in landmine-affected regions around the world.

Course leader: Professor (Col) Jon Clasper, Clinical Lead, Centre for Blast Injury Studies

Training small cohorts of trauma surgeons from landmine-afflicted areas in specialist limb-salvaging techniques, the course was led by *Professor (Col) Jon Clasper*, who has extensive experience of medically treating blast injury victims.

Course organiser: Major Taff Edwards, Royal Army Medical Corps

The course organiser, *Maj Taff Edwards*, is a trauma surgeon in the UK Army, currently finalising his MD(Res) thesis in the Centre for Blast Injury Studies. Taff completed his programme of research in the Centre this year and returned to full-time employment within the NHS as a fellow in ortho-plastics and complex upper limb surgery at Wrightington Hospital. While at the Centre, Taff investigated heterotopic ossification, focussing on the clinical outcomes and complications of amputees from the Afghan conflict.

BSc Surgery and Anaesthesia

Medical students at Imperial College take a year out of standard medical training to conduct a year's study on a specific aspect of medicine. The BSc in Surgery and Anaesthesia one of 14 different specialities offered. The course focuses on the science behind the scalpel; looking at the scientific principles underlying surgical and anaesthetic practice. Military surgeons and researchers Dan Stinner and Phill Pearce were invited to lead the Surgical Innovation module this year. The overall aim of the BSc is to allow intercalating medical students the opportunity to develop an understanding of the important scientific principles that affect every aspect of surgery and anaesthesia from basic molecular mechanisms to the design and interpretation of surgical trials. The innovation module highlights that improvements in clinical practice are increasingly dependent upon the successful design and application of innovative technology. Dan and Phill discussed the challenges of applying conventional research principles to trauma surgery. Lectures included blast injury, limb salvage, amputations and rehabilitative strategies along with a more informal discussion of military and trauma careers. The sessions were well received by an engaged set of students.

Undergraduate Research Opportunities Programme (UROP)

UROP is Imperial College's highly active opportunity for students from within and outside the College who wish to develop an appreciation of research and the environment within which it takes place. Each year the Centre supports a number of students through the programme; furthering the ambitions of undergraduate students, providing supervisory duties to young academics, and expanding the research goals of the Centre. This year we saw two students spend ten weeks in the Centre.

The aim of project one was to look at the mechanical behaviour of an offloading orthotic brace designed to transmit force through the leg instead of the heel. Such a brace is prescribed at the Defence Medical Rehabilitation Centre Headley Court, to patients with severe foot and ankle injuries. A finite element model of the brace was developed that was able to simulate compressive loads based on the gait cycle. The modelling identified the effect of stiffness of changeable parts of the brace to the offloading capacity and strength of the brace. In addition, areas of weakness at peak loads during the gait cycles were identified. The preliminary results from this UROP have gone into a funding application to the US Department of Defense (DoD) and communicated to individuals at Headley Court.

Project two investigated the effect of the spacing of perforated metal plates on blast propagation. It was demonstrated that no simple linear relationship exists between spacing and attenuation, the overall effect showing a maximum of mitigation at ~25 mm separation in the 60 mm diameter shock tube. This implies a response which is affected by pulse duration and lateral dimensions, as well as axial spacing. This information is valuable to current shock tube experiments and the response will be modelled and investigated further to enable mitigation design.

Communication of the Work

Media Mentions

- www.gov.uk *3d printing synthetic bones for blast injury research.* April 2016. Refers to a Centre for Defence Enterprise funded project led by Dr Andrew Phillips to develop 3D printed physical representations of lower limb bones for us in assessing blast injuries.
- Focus on Military, a magazine from IrwinMitchell solicitors. *Amputation Rehabilitation Research at Imperial College.* June 2016. Refers to a CBIS open seminar organised by Prof Alison McGregor showcasing some of the work done and yet to be done in the area of rehabilitation in the Centre.

"WE MEASURE OURSELVES BY THE REAL BENEFITS WE MAKE TO VETERANS AND THEIR FAMILIES. WE ARE DIFFERENT FROM OTHER RESEARCH CENTRES"

- BLESMA Magazine. *The Boffins of Blast.* Autumn 2016. Refers to an article detailing the work in the Centre for the benefit of amputees.
- Channel 4's Sunday Brunch. October 2016. Dr Emily Mayhew discussed the parallels between today's amputees and the casualties from WW1.
- www.hmsolicitors.co.uk *Centre for Blast Injury Studies.* November 2016. A write up on our Annual Networking Event which focussed on the multidisciplinary approach to the regeneration and rehabilitation of blast injured.
- International Health Magazine. *The biomechanics of blast injuries.* December 2016. An interview with Drs Spyros Masouros and Nic Newell about their work to identify spinal blast injury patterns and their prevention.

Amputation Rehabilitation Research At Imperial College

As I listened to Dr. Emily Mayhew, Historian in Residence, Department of Bioengineering at Imperial College speaking on Front Row about the new Wounded Exhibition at the Science Museum, I was reminded that I first encountered Emily on BBC Radio 4 when she was talking about the research on the life-long cost and commitment to military amputees.

Public Engagement

Imperial Festival & Alumni Weekend May 2016

The first weekend of May marked the College's fifth annual—and largest yet—Imperial Festival, which saw over 500 scientists share the fun and fascination of their research with the public. The Centre's involvement included a stand and talk, both entitled *Insult to Injury: Understanding Blast from Head to Toe*, allowing visitors to explore the effects that explosions have on the body through interactive, funfair-style demonstrations while learning about our multidisciplinary approach to probing the problems surrounding blasts.

Claire Webster (overleaf), who volunteered for the stand during the weekend, describes it as a demonstration of "how basic concepts in science, which children may currently be learning in school, underpin the research work and help to solve problems in blast injury and their effects on the body." Responding enthusiastically to how the stand translated its research and perhaps evoked those school lessons, visitors of all ages had the chance to fire big blasts from the Centre-made, smoke-filled airzooka, grasp the effect of blast on bubbles (i.e. soft tissue) and build a blaster of their own. The Centre's demonstrations also showed how blast injury can be mitigated, all the while ensuring experts in the field were on-hand to speak directly to guests.

Figure 5: Inspiring the researchers of tomorrow: "I was incredibly impressed with the enthusiasm from the youngsters and their knowledge." – Claire Webster, pictured (right)

With 90% of visitors having said that the Festival increased their understanding of research carried out at the College, the Centre's demonstrations and talk given by Phill Pearce and Hari Arora (below) have surely facilitated the public's interest in the Centre's work and aims in fun and engaging ways. Third-time Imperial Festival volunteer Luz Nguyen recalls that "the whole experience was rewarding, especially seeing the audiences' (children and adults alike) amazement and excitement learning about our research at the Centre."

The Centre's participation in the Festival not only raised public awareness of our work, but also led to their participation in that work. A study led by PhD student Sam Smith, for example, got several new participants after being advertised at the stand. Moreover, Festival-goers' interest has led to our researchers being invited to give talks at schools around London, opening up further opportunities for public engagement. As if these positive outcomes weren't enough, the success of the weekend was reignited when the stand and talk were recognised in the first ever post-Festival award's ceremony, with Phill and Hari being awarded the prize for Biggest Explosion.

While the Centre's involvement in the Imperial Festival was beneficial for us, it also served as a testament of how good a forum the Festival is for facilitating scientific curiosity in young people. As Claire highlights, the long-term effects that sharing our work through this medium may prove to be immeasurable: "I was incredibly impressed with the enthusiasm from the youngsters and their knowledge. I think the future seems very bright considering the new young minds that have hopefully now been inspired to be the researchers of tomorrow."

On behalf of the Centre, many thanks to all of the volunteers for your part in engaging the public in the Centre's work by way of the Festival. Because of you, the Centre's stand was a great success (not to mention a blast). Special thanks to Sam Smith for lending us his manikins.

Annual Network & Research Update Event November 2016

Building on previous public presentations of CBIS research programmes, November 2016 saw the largest networking event hosted to date. This was the first event of its kind internationally to address such a broad range of themes relating to contemporary and future challenges in the rehabilitation of military casualties. Attendees included representatives from leading organisations concerned with the future of wounded veterans, led by our patrons, the Royal British Legion, as well as Invictus, BLESMA, Find a Better Way and Help for Heroes. Senior members of both UK and US military and military medical services including the Surgeon General Alasdair Walker, joined rehab specialists from Headley Court, clinicians and scientists from our partner institutions, MPs, journalists, and military veterans to hear Professor Anthony Bull begin with an update on CBIS' research work as our understanding of blast injury moves into a new post-deployment phase. The first speaker, Colonel John Etherington, outlined the extraordinary achievements of DMRC Headley Court in the rehabilitation of the cohort of unexpected survivors with complex trauma from Afghanistan between 2007-14, stressing the need to consolidate and adapt both clinical understanding and patient progress going forward.

An important reminder of the international context of blast injury and its consequences came from Major Daffyd Edwards who described the recent course hosted by CBIS medics and researchers to teach current surgical concepts in traumatic amputations that best serve future rehabilitation demands to surgeons from a range of countries with significant civilian amputee cohorts, including Sri Lanka, Cambodia, Ethiopia, Lebanon, Indonesia, and Kenya. The international perspective continued with a presentation on military rehabilitation in the USA from Dr Dan Stinner, orthopaedic trauma surgeon and former Medical Director of The Center for the Intrepid, United States Army Institute of Surgical Research, who is based in CBIS until 2019 undertaking research on improving long-term outcomes for trauma patients. The first session ended with Professor Alison McGregor describing the cutting edge technology being developed by her department with the aim of improving prosthetic fit and usage for current and future amputee patients, as well as creating a global analytics resource for those patients and their therapists.

After lunch, the science of rehabilitation and severe casualty research was presented. Dr Claire Higgins demonstrated her work on the cellular bioengineering of soft tissues that aims to produce treatments to secure a more resilient and therefore more prosthetically-efficient amputation stump. Major Neil Eisenstein outlined current understanding of heterotopic ossification, a significant cause of pain and prosthetic malfunction for over 60% of military amputees worldwide, and likely similar amounts in the global traumatic amputee population. The session ended with the surgical perspective given by Wing Commander Jon Kendrew, who described some of the new operative techniques for amputee mobility, including osseointegration which offers an alternative to the socket and stump model that has predominated for over a century.

The event was closed with a presentation from General Sir Timothy Granville-Chapman who described the future of rehabilitation through the joint centre at Stanford Hall, due to be completed in

2017. The military element (D**M**RC) will consolidate the work and legacy of Headley Court. The civilian partner will provide a new national (D**N**RC) rehabilitation capability, built on the expertise and achievements developed within the military cadre. After concluding remarks from Professor Bull, the audience remained behind late into the evening, energised by the range of themes covered by the speakers at the event. Discussions and engagements across disciplines and organisations were additionally stimulated by the background of an exhibition of photographs© taken at Headley Court in 2016 by award-winning army photographer Rupert Frere.

Subject Specific Meetings

NATO HFM 271 Meeting and Human Injury Assessment in Vehicle Explosions Symposium June 2016

Dr Spyros Masouros hosted a weeklong event that included the first NATO HFM 271 meeting as well as a two-day symposium on Human Injury Assessment in Vehicle Explosions, during which over 50 attendees came to listen to speakers from around the globe. Of the event, Dr Masouros said:

> *The symposium had a great turnout from the blast injury biomechanics community, being one of the rare occasions where the primary stakeholders of focussed research sit in the same room to discuss that research. The event proved to be a unique forum for dissemination and networking, underscoring the Centre's leadership in blast injury and protection research to ensure that we are part of the very few shaping the future in this domain*.

Colt Foundation Research Meeting | December 2016

The annual Colt Foundation Research Prize meeting, held by the Military Medicine Section of the Royal Society of Medicine, is the highlight of the military academic calendar, showcasing the current research underway within the Defence Medical Services. The meeting concludes with the Colt Research Prize, which provides six selected finalists the opportunity to present their research from any aspect of Military Medicine. This years' theme was 'Innovation and Technology within Health Services.

The meeting was opened by Brigadier Tim Hodgetts, who provided a wonderful presentation demonstrating the importance of research in defence engagement with multiple organisations at home and overseas. He communicated how using the universal language of medicine and, in particular, medical innovation, we can collaborate and develop strong relationships with the National Health Services, medical teams in other nations, and military medical teams in armed forces abroad. He also communicated potential barriers to innovation, such as resistance to change, lack of motivation and failure to work as teams and work together. Overcoming these barriers is key to success in research.

The morning's session also included a presentation from Professor Steve Goodacre, Emergency Medicine physician, who discussed technology and how it can transform and streamline medical care, maximise productivity, improve outcomes, and ensure patient safety. Professor Tim Evans, National Director of Clinical Productivity, then presented the findings in The Carter Report, a document outlining how improvements to the NHS can be made by restructuring services, and utilising personnel more effectively.

Following this, six of the highest scoring posters selected for oral presentations were heard, and the standard, as usual was of the highest calibre. Of these, Major Taff Edwards from the Centre for Blast Injury Studies, presented his fascinating work on heterotopic ossification from his MD studies within the centre. Lunch and further posters were displayed for perusal, with researchers discussing their projects with passing delegates, speakers and judges.

The afternoon presentations included Sqn Ldr Claire Webster, also of the Centre for Blast Injury Studies, who presented the advantages and challenges of undergoing research, the process of application, being successful and productive during your research, and completing your thesis. In addition, Mansour Khan, consultant surgeon at Imperial College London, and Senior Lecturer to the Academic Department of Military Surgery and Trauma discussed his experience of undergoing his PhD studies later in his career. Both presentations were a valuable insight into the world of military academia.

The final session of the day comprised of the presentations from six candidates chosen by the panel to have represented the highest calibre of research within the Defence Medical Services. The standard at this conference improves year on year, and this year was no exception.

The Centre for Blast Injury Studies will continue to have a strong involvement with this annual meeting, both with supporting researchers to contribute to this prestigious day, and providing knowledgeable speakers to present regarding the wider issues within defence research, and continue to propagate the importance of innovation and research to progress and improvement in outputs within medicine.

Publications

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Grigoriadis G, Newell N, Carpanen D, Christou A, Bull AMJ, Masouros SD., *Material properties of the heel fat pad across strain rates.* Journal of the Mechanical Behavior of Biomedical Materials. 2016 Vol. 65 pp 398-407.

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Invited Talks

Arora H. *Lung Mechanics Blast Injuries.* Institution of Mechanical Engineers, London, UK. November 2016.

Bull A. *The Royal British Legion Centre for Blast Injury Studies.* Friends of Millbank Lecture. Former Royal Army Medical College, London, UK. September 2016.

Clasper JC. *Pelvic Fractures.* Dstl Preparedness Meeting. Birmingham, UK. March 2016.

Clasper JC. *Military Extremity Trauma, Contemporary Trauma: Responding to Current Terrorist Threat.* University Hospital of Wales Cardiff, UK. April 2016.

Clasper JC. *Blast Injury Research and Development in Force Protection.* RAF Medical Service Symposium. Halton, UK. June 2016.

Clasper JC. *Blasted Bones; Skeletal Failure after Explosion.* BORS Glasgow, UK. September 2016.

Henson D. *Rebuilding Broken Bodies.* James Clayton Lecture. Institution of Mechanical Engineers, London, UK. October 2016.

Masouros SD. *The Royal British Legion Centre for Blast Injury Studies.* Science in Parliament. Portcullis House, London, UK. December 2016.

Mayhew E. *The show without a bullet: Blast injury.* Know It Wall. February 2016 *www.knowitwall.com/audiodoc/blast_injury*

Mayhew E. *Blast Injury in the 21st Century.* Pint of Science Festival. University of Bristol, UK. May 2016.

Mayhew E. *Rebuilding a Hero.* The Time Cheltenham Science Festival. Cheltenham, UK. June 2016.

Mayhew E. *History of military plastic surgery.* Combined Services Plastic Surgery Services Annual Conference. London, UK. September 2016.

Mayhew E. *Medicine at the Battle of the Somme.* Association of Anaesthetists of Great Britain and Ireland annual lecture. London, UK. October 2016.

Mayhew E. *Commemorating Medicine at the Somme.* Nuffield History Group. London, UK. November 2016.

Mayhew E. *A Century of Military Medicine.* The Princes' Teaching Institute. London, UK. December 2016.

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Pearce P, Sharrock A, Webster C. *The Royal British Legion Centre for Blast Injury Studies*. APPG-EW Mine Action Event. Speakers Green, London, UK. April 2016.

Proud WG. *Blast Processes and Blast Injury.* MACH Conference. Annapolis, USA. April 2016.

Proud WG. *Blast and Shock Propagation in Granular Media.* Explosive Welding and Material Synthesis Seminar. Coimbra, Portugal. June 2016.

Proud WG. *Dynamic Loading of Biological Specimens.* Dynamic Properties of Materials Seminar. Poznan, Poland. August 2016.

Proud WG. *Modelling and Output Measurement of Polymer Bonded Explosives.* Explosives and High Speed Phenomena Meeting. Beijing, China. September 2016.

Proud WG. *The Dynamic and Blast Loading of Biological Materials.* ImPlast Conference. New Delhi, India. December 2016.

Conference Presentations

12th World Congress on Computational Mechanics. Seoul, South Korea. July 2016.

Villette CC, Phillips ATM, *Surrogate poroelastic microscale representation of bone remodelling to inform an efficient structural mesoscale bone adaptation model.*

Colt Foundation Annual Research Meeting. Royal Society of Medicine. London, UK. December 2016.

Pearce AP, Bull AMJ, Clasper JC. *Investigating the visceral response to underbody blast loading.*

Combined Services Orthopaedic Society (CSOS) Annual Conference. Plymouth, UK. May 2016.

Bonner TJ, Masouros SD, Newell N, Ramasamy A, Hill AM, West ATH, Clasper JC, Bull AMJ. *The effect of knee position on the severity of lower limb injuries in an under-vehicle explosion: a cadaveric study.*

Edwards DS, Rosenberg N, Karunaratne A, Clasper JC, Bull AMJ. *The biomechanics of blast related amputee Heterotopic Ossification computation modelling and physical experiments.*

Spurrier E, Masouros SD, Clasper JC. *The effect of posture on vertebral fracture patterns in a simulated* underbody blast loading scenario.

Webster C, Masouros S, Clasper JC. *Traumatic amputations and pelvic fracture: is a mechanistic link key to increase future survivors?*

Government Experts on Mitigation Strategies (GEMS) Annual Meeting, London, UK. January 2016.

Webster C, Masouros SD, Clasper JC. *Mapping the Blast Pelvis.*

International Research Council on the Biomechanics of Injury (IRCOBI), Malaga, Spain. September 2016.

Carpanen D, Kedgley A, Plant D, Masouros SD. *The risk of injury of the metacarpophalangeal and interphalangeal joints of the hand.*

Grigoriadis G, Carpanen D, Bull AMJ, Masouros SD. *FE model of the foot and ankle for injury prediction in underbody blast.*

Newell N, Grigoriadis G, Christou A, Carpanen D, Masouros SD. *Mechanical characterisation of bovine intervertebral discs at a range of strain rates.*

International Surgical Congress of the Association of Surgeons of Great Britain and Ireland. Belfast, UK. May 2016.

Sharrock AE, Barnett-Vanes A, Rickard R, Rankin SM. *Blast trauma increases microvesicle shedding in an in-vivo model of thoracic blast trauma.*

Webster C, Masouros S, Clasper JC. *Traumatic amputations and pelvic fracture: is a mechanistic link key to increase future survivors?*

Military Health Systems Research Symposium (MHSRS). Orlando, Florida, USA. August 2015.

Pearce AP, Bull AMJ, Clasper JC. *Patterns of non-compressible torso haemorrhage amongst mounted UK forces.*

SpineWeek Singapore. May 2016.

Christou A, Masouros SD. *Effect of posture on injury of the thoracolumbar junction under axial loading.*

Trauma Innovation. London, UK. September 2016.

Nguyen TT. *Blast biophysics.*
Singleton J. *How do explosions cause limb loss?*
Spurrier E. *Spinal injury patterns associated with blast injury.*
Clasper J. *Blast pelvic injury.*
Ramasamy A. *Blast foot and ankle injury patterns.*
Masouros SD. *Vehicle blast injury mitigation strategies.*
Webster C. *Pelvic injury: new ideas on the mechanisms of injury.*
Bonner T. *A mechanistic approach to lower limb blast injuries.*

Exemplar Research Findings

The Centre is committed to transparency in its activities and one of its main outputs is publication in the open literature. This section of the report is a summary of some of the key published journal articles summarising the Centre's research findings in 2016. It highlights the varied yet focused work being undertaken in the Centre, as well as its wide reaching interdisciplinary audience.

As research activities in the Centre are clinically led, no one study is undertaken without prior assessment of clinical data in order to identify the clinical problem and determine appropriate research questions. The presence of military medical staff in the Centre is key to the interrogation of this data which drives further studies involving physical experimentation and computational modelling. The Centre's clinical involvement has developed significantly over the past year with continued and expanded involvement of the Defence Professor of Surgery, Surgeon Captain Rory Rickard and significant contributions from Maj Dan Stinner, exchange officer from the US Army.

Injuries are recreated in the laboratory and can be computer simulated for a variety of environments and conditions to further the understanding of the injury mechanism. Once the mechanism of injury is determined, protective equipment can be assessed or designed to mitigate its effects. Treatment and rehabilitation options can be examined and varied in order to improve the outcomes of those who have suffered injury. The following pages detail some of our key 2016 research findings which can be summarised as follows:

Injury profiles

From the analysis of 40 years of terrorist bombings around the world, we have been able to identify injury patterns and trends associated with terrorist bombings. The nature of these attacks is improvised and the victims mostly civilian. As such, the cases offer invaluable information in relation to the effect of environment on the injuries sustained. Knowledge of incident types and injury patterns can guide the immediate response and medical treatment of the injured, as well as focus research efforts in the investigation of blast injuries. Civilian blast injuries are important to the military for many reasons; UK military trauma surgeons also work in the National Health Service and so their expertise doesn't only benefit UK civilians, but working in the civilian trauma domain also helps to maintain and develop military expertise. This is described in our education section under LIVEX.

Surrogates

A significant challenge in the use of surrogates is accuracy. We use surrogates to improve our understanding of the pathophysiology of human injury and of predicting injury risk. Standardised Anthropomorphic Test Devices (ATDs) and equivalent injury thresholds for blast related loading only exist for assessing the protective efficacy of light armoured vehicles. There is a limited amount of surrogates for investigating the effects of primary blast. We have developed and validated a fast running numerical model of the Military Lower Extremity (MIL-Lx) ATD that can be used to assess injury risk in an under vehicle explosion which will contribute to mitigation design and the improvement of surrogates.

Material properties

Knowledge of the properties of biological materials improves the accuracy and biofidelity of finite element models used in the prediction of injury. We have quantified the material properties of the heel fat pad, an ill understood structure in the foot that sustains significant injury with poor outcomes in under-vehicle explosions. Knowing the properties of this material across a range of loading rates contributes to the finite element models that are used as design tools for developing mitigation technologies.

Computational simulation and modeling

Scientific discovery or understanding involves the formulation of theory to explain observed phenomena, the design and execution of experiments to test theory and the feedback of experimental results to evolve theory. Modeling and simulation live at the intersection between theory and experiment, offering additional insights that are often impractical or impossible to discover through real-world experimentation. Key developments this year include the ability to accurately model bone fracture across different loading rates and for different loading conditions. This fundamental modelling study will allow mitigation to be tested *in silico.* We continue to use these tools to assess and predict the effect of forces on the musculoskeletal system in order to design optimal protective equipment, rehabilitation strategies and influence surgical planning.

Primary blast lung

This year significant advances were made in our study of injury to the lungs during an explosion. Techniques were developed to enable the efficient identification and quantification of all major leukocytes in our rodent model of pulmonary inflammation, offering a platform for greater consistency in the identification of inflammation. Our immunology study showed that the presence of monocytes, in addition to the prediscovered neutrophils, are detected post blast which could offer clinicians an additional triage tool to those at risk of deleterious systemic immune activation. Understanding the immune response is critical to patient management and avoiding complications due to treatment.

40 years of terrorist bombings – a meta-analysis of the casualty and injury profile.

Edwards DS, McMenemy L, Stapley SA, Patel HDL, Clasper JC. (2016)
Injury – International Journal of the Care of the Injured. Vol. 47 Iss.35 pp 646-652

Terrorists have used the explosive device successfully globally for years. Suicide bombings in particular are being increasingly deployed due to the devastating effect of a combination of high lethality and target accuracy. This study demonstrates that terrorist bombings are increasing and remain a real threat to civilian personnel around the world. This study firstly assessed the open source Global Terrorist Database (GTD) throughout its entire timeline (from 1970). Variables chosen included date of incident, country of incident, suicide or non-suicide detonation and death and wound rates. In addition, a Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) search was performed using two separate resources (PubMed and Embase). This identified research articles that examined injury patterns and casualty figures from terrorist bombings worldwide. Key search terms such as "terrorist" and/or "suicide" and/or "bombing" were used. Primary (audiovisual, lecture, book, biography publications) and secondary (letters, retracted articles, comments, editorials, conference papers) exclusion criteria were used to filter the search. Where duplication of incidents was found between two or more articles, data was extracted and separated. Statistical analysis was performed using Student's t-test when comparing the means of normally distributed continuous data using SPSS Statistics Version 20.1 with significance set at p<0.05.

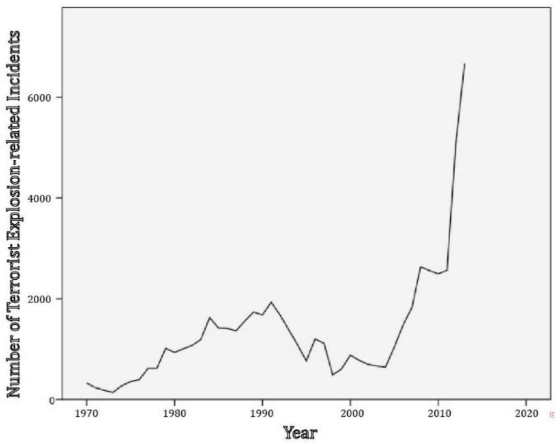


Figure 6: Number of terrorist explosion related incidents worldwide per year since 1970

BLAST MECHANISM	INJURY TYPE	MEAN (SD)	% OF TOTAL INJURIES
PRIMARY	Blast Lung	17.70 (±29.01)	6.77
	Tympanic Membrane Injury	38.63 (±56.17)	14.77
SECONDARY	Gastrointestinal Tract	1.25 (±1.64)	0.47
	Thorax	21.70 (±27.82)	8.30
	Abdomen	13.92 (±23.34)	5.32
	Head and Neck	80.36 (±205.19)	17.45
	Extremity	49.59 (±70.07)	18.96
TERTIARY	Fracture	26.66 (±25.47)	10.19
	Amputation	6.63 (±8.54)	2.53
QUATERNARY	Burns	39.74 (±53.98)	15.19

Table 1: Mean number of injuries by subtype, and total as percentage, per incident.

The aim of the study was to identify trends and analyse the demographics and casualty figures in global terrorist related explosive incidents worldwide. This has shown an increasing trend (Figure 6) and allowed the identification of injury patterns (Table 1) in almost five decades worth of incidents. Extremity, head and neck, and hearing related injuries account for the most significant numbers of injuries to date.

Meta-analysis as a means of predicting injury

- Civilian blast injuries replicate those seen amongst armed forces personnel and are increasing in number.
- The triage and management of patients from terrorist explosions represents a challenge to clinicians due to the diverse mechanisms of injury.
- Knowledge of incident types and injury patterns can guide the immediate response and medical treatment of the injured, as well as focus research efforts in the investigation of blast injuries.
- Lessons learned from blast injury management is a two-way process between military and civilian clinicians, scientist and engineers.

Trauma-related amputations in war and at a civilian major trauma centre – comparison of care, outcome and the challenges ahead.

Edwards DS, Guthrie HC, Yousaf S, Cranley M, Rogers BA, Clasper JC. (2016)
Injury. Vol. 47 Iss.8 pp 1806-1810

The Afghanistan conflict resulted in a large number of service personnel sustaining amputations, due to Improvised Explosive Devices. Innovation in combat casualty care, personal protective equipment and casualty evacuation resulted in increased survivorship of complex trauma. Subsequent resuscitation and trauma transfusion protocols were improved, along with the delivery of consultant led care, and immediate damage control surgery. As a consequence, it has been reported that survivorship increased year on year throughout military operations in Afghanistan. These lessons learned and advances made in medical care in Camp Bastion have since been incorporated into NHS care. Whilst obvious differences exist between military and civilian trauma-related amputations, both environments result in life changing injuries. This study compares military and civilian trauma related amputees to assess differences in management, care and outcomes in order to identify the challenges ahead.

A significant difference was seen in median age, mean numbers of amputations per casualty and gender. The military cohort was younger (18-43) compared to the civilians (24-87). They sustained more amputations per casualty (1.6 compared to 1) and were predominantly male (99% compared to 78%). Despite a worse injury profile, rehabilitation outcomes for military amputees far exceed those achieved in the civilian setting (91% Grade E+ compared to 19%). Combat casualty care is consultant delivered from the point of wounding, evacuation, resuscitation and surgery through to rehabilitation. Civilian casualties are treated at the scene by a paramedic and moved to a Major Trauma Centre for resuscitation and surgery within the hour. Because there is no dedicated rehabilitation unit with the NHS environment, amputees are referred to a local prosthetic and amputee rehabilitation service for consideration of prosthesis. The rehabilitation process if broadly divided into five stages over a one year period.

Amputations among civilians are low in number bur represent a significant macro-economic cost with prolonged in-patient stay and high proportion of patients requiring multi-speciality input. If this civilian cohort is representative of the wider NHS, there are significant challenges to maximise the functional outcome for amputees. Additional investment is urgently required to support rehabilitation within civilian trauma and prosthetic centres in the UK. Experiences of both military and civilian pathways may allow lessons learned from either cohort to benefit each other.

Comparing amputee care and outcomes at war and in the civilian setting

- While obvious differences exist between military and civilian trauma related amputations, both settings result in life changing injuries.
- Differences in the military trauma system, and a high sustained investment in rehabilitation are contributing factors for differing outcomes in military and civilian amputees.
- The analysis of experiences of military and civilian care pathways may allow lessons learned from both domains to benefit each other.

In vivo knee contact force prediction using patient-specific musculoskeletal geometry in a segment-based computational model.

Ding Z, Nolte D, Tsang CK, Cleather DJ, Kedgley AE, Bull AMJ. (2016)
Journal of Biomechanical Engineering – Transactions of the ASME. Vol.138 Iss 2 pp 1018-1 – 1018-9

Segment based musculoskeletal models of the lower limb allow the prediction of muscle, joint and ligament forces without making assumptions about joint constraints. The dataset published for the "Grand Challenge Competition to Predict *In Vivo* Knee Loads" provides a large dataset of directly-measured tibiofemoral contact forces for different activities of daily living for subjects with instrumented knee implants. For validation, the segment based musculoskeletal model was used for predictions for activities of daily living (normal gait, squat and sit-to-stand) for three different subjects for which data were available. Comparisons of the predictions with measured tibiofemoral contact forces showed root mean square errors between 0.48 and 0.65 times BW for gait trials. These compare to literature values of 0.48 to 0.69 times BW. The results for squat (0.46-1.01 BW) and sit-to-stand (0.70-0.99) were of similar magnitude. This study shows that segment based musculoskeletal models using patient-specific geometry can be used for a variety of activities of daily living for accurate predictions of muscle and joint forces; this technology forms the basis for much of the rehabilitation research in the Centre.

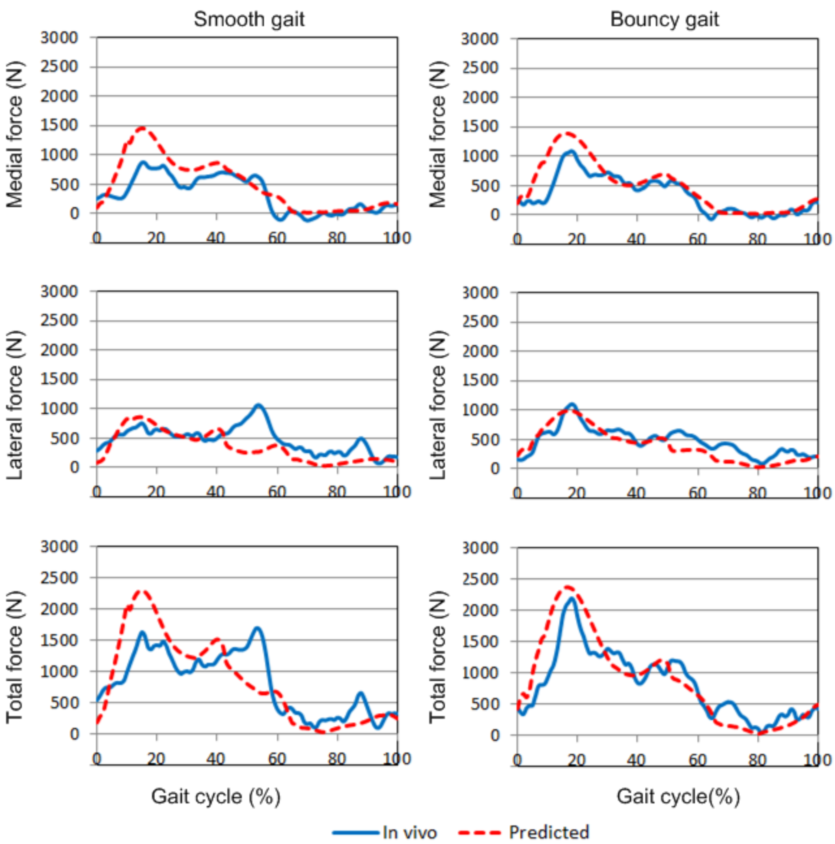


Figure 7: Unblinded model predictions of medial, lateral and total tibiofemoral contact forces compared with *in vivo* measurements obtained during two different gait trials.

Designing optimal rehabilitation strategies

- Valuable information in the lower limb musculoskeletal system such as the muscles and articular surface loading during actives of daily living was obtained and validated.
- The subject-specific musculoskeletal modelling can be applied to design optimal rehabilitation strategies for traumatic amputees and decision making for surgical planning.

Material properties of the heel fat pad across strain rates.

Grigoriadis G, Newell N, Carpanen D, Christou A, Bull AMJ, Masouros SD. (2016)
Journal of the Mechanical Behavior of Biomedical Materials. Vol. 65 pp 398-407

Intra-articular fractures with high rates of amputation and poor outcome are commonly observed in under-vehicle explosions. These are associated with the 'deck-slap' injury that occurs due to the floor of the vehicle deforming rapidly above the explosion. Energy is transferred from the floor to the hind foot through the heel fat pad, a 'honeycomb' structure consisting of fibrous tissue and fat globules, which determines the transmission of plantar loading to the lower limb. Although the energy damping capacity of the fat pad is considered to be crucial in locomotion, its material behaviour at loading rates associated with injury is not documented. The aim of this study was to quantify the non-linearly viscoelastic material properties of the human heel fat pad across strains and strain rates. An inverse finite element (FE) optimisation algorithm was developed and used, in conjunction with quasi-static and dynamic tests (Figure 8) performed on cadaveric heel specimens, to derive specimen-specific and average non-linearly viscoelastic material models able to accurately predict the response of the tissue at compressive loading of strain rates up to 150 s^{-1}; these are loading rates seen in blast. The mean behaviour was expressed by the quasi-linear viscoelastic (QLV) material formulation (C_{10}=0.1 MPa, C_{30}=7 MPa, K=2 GPa & A_1=0.06, A_2=0.77, A_3=0.02 for τ_1=1 ms, τ_2=10 ms, τ_3=10 s). Results from this study have been used to improve the accuracy of FE models of the lower limb able to simulate underbody blast. These models are currently being used to predict injury, examine the effect of posture in the injurious outcome and assess the efficacy of novel and existing mitigation means.

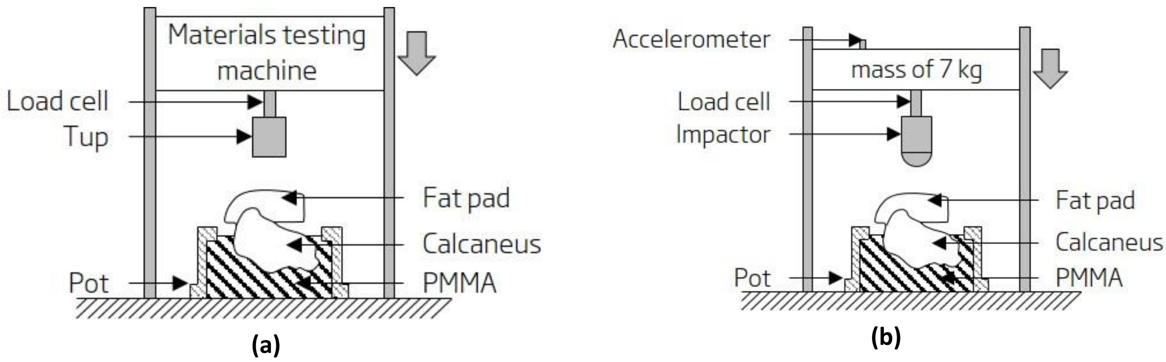


Figure 8: Schematics of the apparatus used for conducting (a) quasi-static and (b) high rate compressive testing on cadaveric human heel fat pad samples.

Loading from underbody blast is transmitted through the heel fat pad, a complex and ill-understood structure

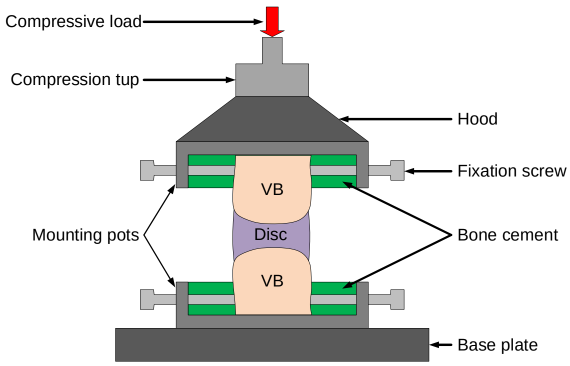
- Foot and ankle injuries are severe and common in under-vehicle explosions. To mitigate the outcome we need to understand the behaviour of each structure, such as the heel fat pad.
- This study quantified the material properties of the heel fat pad across loading rates and found that the material stiffens significantly as strain rate increases.
- The results were used to increase the biofidelity of computational models of the foot and ankle in predicting the response of the lower limb in under-vehicle explosion scenarios.
- These models can be used as design tools for developing mitigation technologies.

Material properties of bovine intervertebral discs across strain rates.

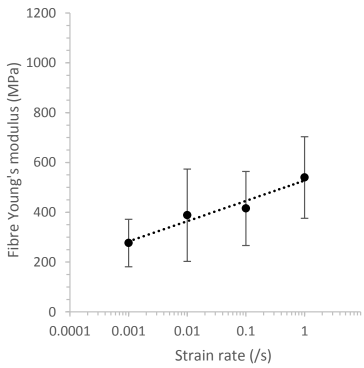
Newell N, Grigoriadis G, Christou A, Carpanen D, Masouros SD. (2016)
Journal of the Mechanical Behavior of Biomedical Materials. Vol. 65 pp 824-830

Spinal injury patterns caused by under-vehicle blast have previously been studied in the Centre for Blast Injury Studies (Spurrier et al. 2015, Spine), and work towards developing a computational model of the whole human spine is on-going. The accuracy of this model will be dependent on the precision of material models of the components of the spine. One of the most complex components, and the one that is responsible for allowing the spine to bend and twist while simultaneously distributing compressive loading to adjacent vertebrae is the intervertebral disc. To study the mechanical behaviour of individual components of the intervertebral disc, it has been common for specimens to be dissected away from their surrounding tissues for mechanical testing. However, disrupting the continuity of the intervertebral disc to obtain material properties of each component separately may result in erroneous values.

In this study, an inverse finite element (FE) modelling optimisation algorithm has been used to obtain material properties of the intervertebral disc across strain rates, therefore bypassing the need to harvest individual samples of each component. The technologies for this inverse approach were developed as part of other CBIS work presented on the previous page. Uniaxial compression was applied to ten fresh-frozen bovine intervertebral discs at a range of strain rates (Figure 9a). The experimental data were fed into the inverse FE optimisation algorithm and each experiment was simulated using FE models. A sensitivity analysis revealed that the intervertebral disc's response was most dependent upon the Young's modulus (YM) of the fibre bundles and therefore this was chosen to be the parameter to optimise. Based on the obtained YM values for each test corresponding to a different strain rate ($\dot{\varepsilon}$), the following relationship was derived: $YM = 35.5 \ln \dot{\varepsilon} + 527.5$ (Figure 9b). These properties can now be used in finite element models of the spine.



(a)



(b)

Figure 9: (a) Diagram of the experimental setup allowing compression of the vertebral body-disc-vertebral body (VB) specimen, (b) Averaged optimised annulus fibrosus fibres Young's modulus for each of the ten subject-specific models at each strain rate.

Towards a full spine computational model for injury prediction

- An optimisation algorithm utilising an inverse-FE technique performed on subject-specific models allowed strain rate dependent material properties of the disc to be derived.
- Intervertebral discs stiffen with increasing strain rate.
- The results from this study can be used in computational models of the full human spine.

Strain rate dependency of fractures of immature bone.

Cheong VS, Karunaratne A, Amis AA, Bull AMJ. (2016)
Journal of the Mechanical Behavior of Biomedical Materials. Vol. 66 pp 68-76

Radiological features alone do not allow the discrimination between accidental paediatric long bone fractures or those sustained by child abuse. Therefore, there is a clinical need to elucidate the mechanisms behind each fracture to provide a forensic biomechanical tool for the vulnerable child. Four-point bending and torsional loading tests were conducted at more than one strain rate for the first time on immature bone, using a specimen-specific alignment system, to characterise structural behaviour at para-physiological strain rates. The bones behaved linearly to the point of fracture in all cases and transverse, oblique and spiral fracture patters were consistently reproduced. The results showed that there was a significant difference in bending stiffness between transverse and oblique fractures in four-point bending. For torsional loading, spiral fractures were produced in all cases with a significant difference in the energy and obliquity to fracture. Multiple fractures were seen only in bones that failed at high stress or torque for both loading types. This demonstrates the differentiation of fracture patterns at different strain rates. The methods developed here by a PhD student funded from other sources and supported by CBIS researchers will be used to characterise adult bone failure at blast loading rates.

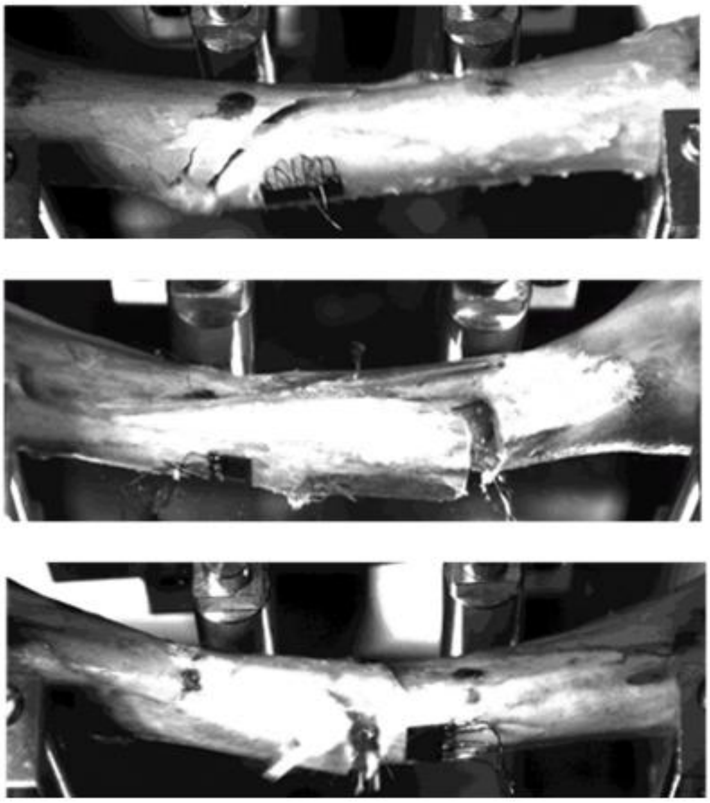


Figure 10: Strain rate effects on bone fracture in found point bending consistently reproduced.

Identifying fracture patterns to determine the injury mechanism

- It is not possible to differentiate between deliberate and accidental fractures even when various injury mechanisms have been proposed.
- This study demonstrates the use of an engineering tool to interpret the injury mechanism for an observed fracture.
- Understanding the injury mechanism for a given fracture pattern enables the development of protective equipment.

A single 9-colour flow cytometric method to characterise major leukocyte populations in the rat: validation in a model of LPS-induced pulmonary inflammation.

Barnett-Vanes A, Sharrock A, Birrell MA, Rankin SM. (2016)
PLOS One 2016; 11(1)

Blast-induced trauma is exacerbated by immune response and the rat is a commonly used model for blast injuries, yet basic research and characterisation of leukocyte populations and sub-sets lags far behind murine research, with inconsistency on reported leukocyte markers and their overlap. These shortcomings limit the opportunity for more complex and advanced rat immunology research. In this study, we developed a robust 9-colour flow-cytometric protocol to elucidate the major blood and tissue rat leukocyte populations, and validated it in a model of LPS-induced pulmonary inflammation for research into blast lung.

Neutrophils, two monocyte subsets, NK Cells, B Cells, CD4+, CD8+ T Cells and alveolar macrophages can be identified simultaneously across different tissues using a 9-colour panel. Neutrophils and monocytes can be distinguished based upon differential expression of CD43 and His48. Neutrophils and CD43Lo/His48Hi monocyte-macrophages are elevated in the lung at 3 and 24 hours during LPS-induced pulmonary inflammation. This validated method for leukocyte enumeration will offer a platform for greater consistency in future rat immunology and inflammation research.

This study provides a framework for consensus in the rat literature regarding leukocyte identification. It highlights the utility of CD43 and His48as two versatile markers, including in discriminating neutrophils and CD43Hi and Lo monocytes. It demonstrates the latter's hitherto unreported selective response to LPS pulmonary inflammation. With other organs such as the spleen, increasingly recognised as major immunological sites capable of giving rise directly to immune cells such as monocyte macrophages that participate in distal inflammatory responses, this panel holds the potential to advance understanding of splenic and hepatic immune contributions in rat models of disease such as trauma.

Identifying biomarkers of the inflammatory response

- The rat is a commonly used model for immunological investigation post trauma, including blast.
- A 9-colour FCM panel to enable efficient identification and quantification of all major rat leukocytes has been developed.
- This study offers a platform for greater consistency in inflammation research.

CD43Lo classical monocytes particles in the cellular immune response to isolated primary blast lung injury.

Barnett-Vanes A, Sharrock A, Arora H, Eftaxiopoulou T, Macdonald W, Bull AMJ, Rankin SM. (2016)
Journal of Trauma and Acute Care Surgery. Vol. 81 Iss.3 pp 500-511

Understanding the cellular immune response to primary blast lung injury (PBLI) is limited, with only the neutrophil response well documented. In this study a rodent model of isolated primary blast lung injury was used to investigate the acute cellular immune response to isolated PBLI in the circulation and lung, including the monocyte response. Distal subacute immune effects in the spleen and liver were also investigated.

Lung histology confirmed pulmonary barotrauma and inflammation. This was associated with rises in CXCL-1, interleukin 6 (IL-6), tumour necrosis factor α and albumin protein in the BALF. Significant acute increases in blood and lung neutrophils and CD43Lo/His48Hi (classical) monocytes/macrophages were detected. No significant changes were seen in blood or lung "nonclassical" monocyte and in natural killer, B, or T cells. In the BALF, significant increases were seen in neutrophils, CD43Lo monocyte-macrophages and monocyte chemoattractant protein-1. Significant increases in CD43Lo and Hi monocyte-macrophages were detected in the spleen at 6 hours.

Blood (Cells/mL)	Median & Interquartile Range	Sham 1hr	PBLI 1hr	Sham 3hr	PBLI 3hr	Sham 6hr	PBLI 6hr
CD43Hi/His48Lo Monocytes	Median	82539	104329	77683	40394	27742	61696
	25% Percentile	34407	71822	7365	19262	23540	32852
	75% Percentile	139336	152889	150858	106438	107276	77251
NK Cells	Median	82539	73080	96244	63903	45727	60728
	25% Percentile	48396	67907	15135	24477	23387	48603
	75% Percentile	139336	152889	131272	131715	52491	67608
B Cells	Median	207331	224267	129759	168887	384120	531546
	25% Percentile	121306	138666	20374	133000	138877	297822
	75% Percentile	317669	272863	419724	353528	562178	615792
CD3 T Cells	Median	356367	521922	446889	646878	576296	714542
	25% Percentile	230235	281162	145389	566275	484594	268280
	75% Percentile	592547	734886	583374	868168	887884	1734000
CD4 T Cells	Median	152360	226589	233081	325103	353035	373349
	25% Percentile	115091	122239	92492	271285	258268	286911
	75% Percentile	252083	273462	303060	487723	581299	992109
CD8 T Cells	Median	137679	183404	171384	219051		
	25% Percentile	70415	112168	36647	175112		
	75% Percentile	167766	193717	216090	336104		

Table 2: CD43Hi/His48Lo monocyte macrophages and NK, B and T cells at 1, 3 and 6 hours in the blood and lung. Data are at 1 hour n=7-8; at 3 hours n=6-7; at 6 hours n=5, in each group from two to three independent experiments presented as median ±25th and 75th percentiles where **p*<0.05 and ***p*<0.01

This study reveals a robust and selective response of CD43Lo/His48Hi (classical) monocytes, in addition to neutrophils, in blood and lung tissue following PBLI. An increase in monocyte-macrophages was also observed in the spleen at 6 hours. This profile of immune cells in the blood and BALF could present a new research tool for translational studies seeking to monitor, assess, or attenuate the immune response in blast-injured patients.

Can we identify patients of primary blast lung injury?

- Blast exposed patients present with a myriad of clinical injuries and symptoms, which can complicate simple and rapid triage.
- This study presents evidence to suggest CD43 Lo classical monocytes and neutrophils can be detected in the blood after Primary Blast Lung Injury.
- This could offer clinicians an additional triage tool to identify those at potential risk of deleterious systemic immune activation.

Prolonged but not short-duration blast waves elicit acute inflammation in a rodent model of primary blast limb trauma.

Eftaxiopoulou T, Barnett-Vanes A, Arora H, Macdonald W, Nguyen TTN, Itadani M, Sharrock AE, Britzman D, Proud WG, Bull AMJ, Rankin SM. (2016)
Injury – International Journal of the Care of the Injured. Vol. 47 Iss.35 pp 625-632

It is well documented that trauma produces an inflammatory response. This study demonstrates that application of blast waves to the limb can elicit a systemic inflammatory response characterised by changes in circulating inflammatory cells and cytokines. An *in vivo* rodent model of primary blast trauma was developed, where shock wave loading was isolated to the lower limb of the test specimen. The loading profile sustained by the limb was well-characterised and delivered quantitative data when describing blast loading in the context of the resultant biological response. Two time points were reported in this article (at 6 and 24 hours post-trauma), highlighting the transient nature of the inflammatory process. Multiple inflammatory markers were screened from the blood and blood plasma. Three different blast groups were explored, where the total energy delivered to the limb differed due to the intensity and/or duration of pulse delivered. The effect of shock wave intensity and duration on inflammation were highlighted, since they are readily influenced in the real world blast event by the explosive type, size, location and environment in which it is delivered.

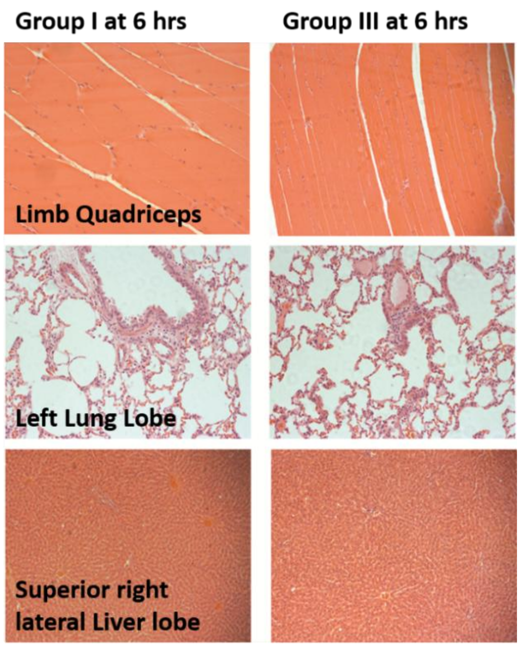


Figure 11: Histological sections of muscle, lung and liver tissue. Quadriceps muscle, left lung lobes and superior right lateral liver lobes were fixed in formalin, embedded in a wax block, cut and stained with Hematoxylin and eosin (H&E) stain. Slides were imaged under a light microscope at 10x magnification.

It was clear that no other primary injuries were sustained during our experiments, evidenced by the histological analysis from each test group as well as multiple other physiological assessments during and after each experiment. Therefore all inflammation related activity arose due to systemic response to lower limb trauma alone.

Knowledge of inflammation is key to treating trauma

- Primary blast injuries are often thought of as pure physical trauma. This study highlighted the real and significant secondary effects that the victim could sustain in the form of inflammation.
- Understanding the immune response is crucial with regard to patient management and ensuring no further complications with treatment.

On the behaviour of lung tissue under tension and compression.

Andrikakou P, Vickraman K, Arora H. (2016)
Nature Scientific Reports 2016; 6:36642

To study the response of the body in trauma, it is important to characterise the mechanical behaviour of the constituent tissues. This study focuses on the mechanical behaviour of lung tissue under tension and compression. Two species were studied to describe interspecies differences in mechanical behaviour with respect to their compositional and architectural differences. Often animals are used as surrogates for human tissues, therefore this is the first in a series of studies aiming to highlight mechanical behaviour of lung tissue and how to translate our understanding of animal tissues to human tissues.

This initial study focused on establishing a test method for quasi-static test rates prior to extending to dynamic rates: 0.25, 2.5 and 25 min^{-1}. Full stress-strain data is reported (Figure 12). A nonlinear viscoelastic analytical model was also implemented to support the use of our data in numerical models in the future. From our results, differences in mechanical response were clear between the rat and rabbit tissues studied; both behaved differently in compression compared to tension. The rabbit tissues seemed to produce a more viscous response compared to the rat tissues. This outcome is to be explored further at higher strain rates.

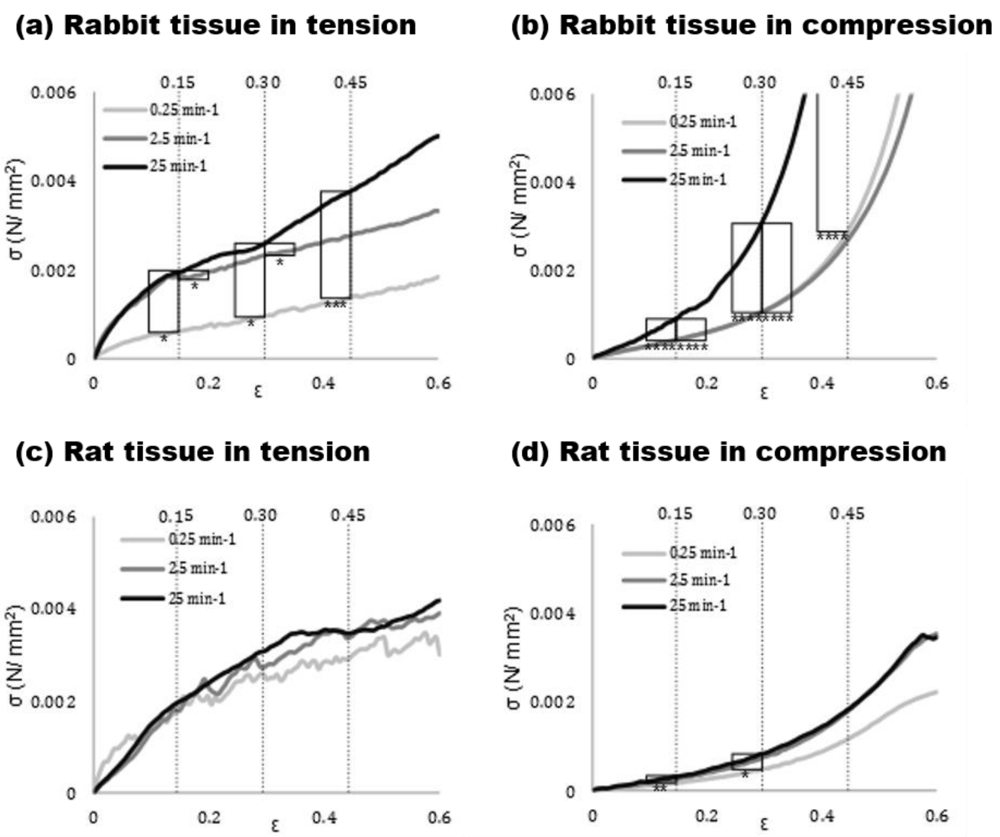


Figure 12: Mechanical test data for rabbit tissue under (a) tension and (b) compression; and rat tissue under (c) tension and (d) compression. Average data is presented with significance evaluated between strain rates: P<0.05*, P<0.01, P<0.005*** and P<0.0001******

Are animals an appropriate surrogate for human tissue?

- Development of physical and numerical models of trauma are reliant on good tissue mechanical properties data.
- This paper identified inherent differences between animal tissues and collected valuable data for future models.

A validated numerical model of a lower limb surrogate to investigate injuries caused by under vehicle explosions

Newell N, Salzar R, Bull AMJ, Masouros SD. (2016)
Journal of Biomechanics. Vol. 49 Iss. 5 pp 710-717

Under-vehicle explosions often result in injury of occupants' lower extremities. The majority of these injuries are associated with poor outcomes. The protective ability of vehicles against explosions is assessed with Anthropometric Test Devices (ATDs) such as the MIL-Lx, which is designed to behave in a similar way to the human lower extremity when subjected to axial loading. It incorporates tibia load cells, the response of which can provide an indication of the risk of injury to the lower extremity through the use of injury risk curves developed from human cadaveric experiments.

In this study an axisymmetric finite element model of the MIL-Lx with a combat boot was developed and validated. Model geometry was obtained from measurements taken using digital callipers and rulers from the MIL-Lx, and using CT images for the combat boot. Appropriate experimental methods were used to obtain material properties. The model was validated by comparing force-time response measured at the tibia load cells and the amount of compliant element compression obtained experimentally and computationally using two blast-injury experimental rigs. Good correlations between the numerical and experimental results were obtained with both. This model can now be used as a virtual test-bed of mitigation designs and in surrogate device development.

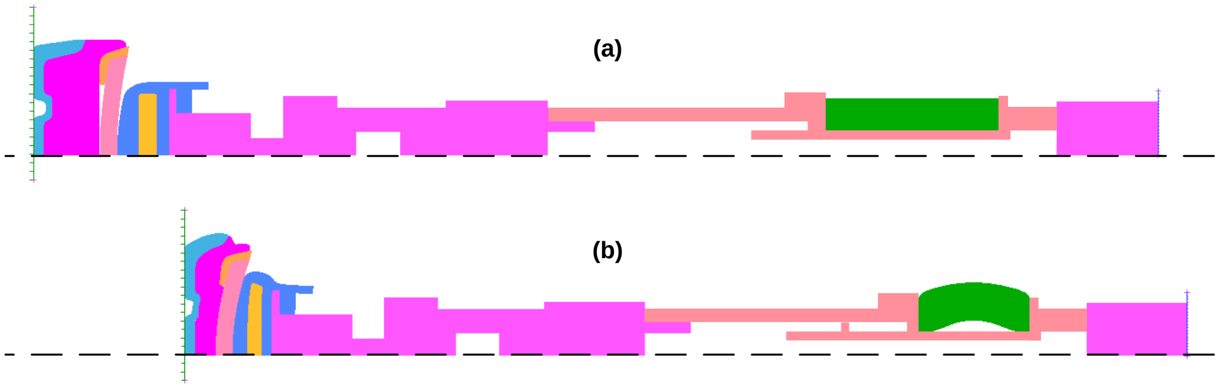


Figure 13: Snapshots of the computer model of the MIL-Lx ATD (a) at the start of a simulation and (b) at the time of peak force. Note the model is axisymmetric with the line of symmetry shown by the dashed line. The combat boot is the right of the images, and the knee joint to the left.

Development of a computer model able to predict lower limb injuries

- This study outlines the development and validation of a fast-running axisymmetric numerical model of the MIL-Lx Anthropometric Test Device that can be used to assess injury risk in an under-vehicle explosion.
- The model has potential applications in both mitigation design and surrogate development.

The dynamic behaviour of the floor of a surrogate vehicle under explosive blast loading.

Newell N, Neal W, Pandelani T, Reinecke D, Proud WG, Masouros SD. (2016)
Journal of Materials Science Research. Vol. 5 Iss. 2 pp 65-73

In order to gain a greater understanding of the mechanisms of lower limb injuries experienced by occupants during under vehicle explosions an understanding of how the vehicle floor behaves is required. In collaboration with CSIR, South Africa, explosive loads between 1 and 6 kg TNT were detonated beneath a vehicle floor surrogate (Figure 14), resulting in peak floor velocities between 5.8 and 80.5 m/s reached in a time between 0.10 and 3.13 ms. The data can now be used to (a) test numerical models of blast and its interaction with structures for validity, and (b) ensure that the velocity profiles replicated in a laboratory environment to understand human tolerance to injury are relevant to the blast process. These will ensure that preventive measures are developed based on realistic physical and numerical models of injury.

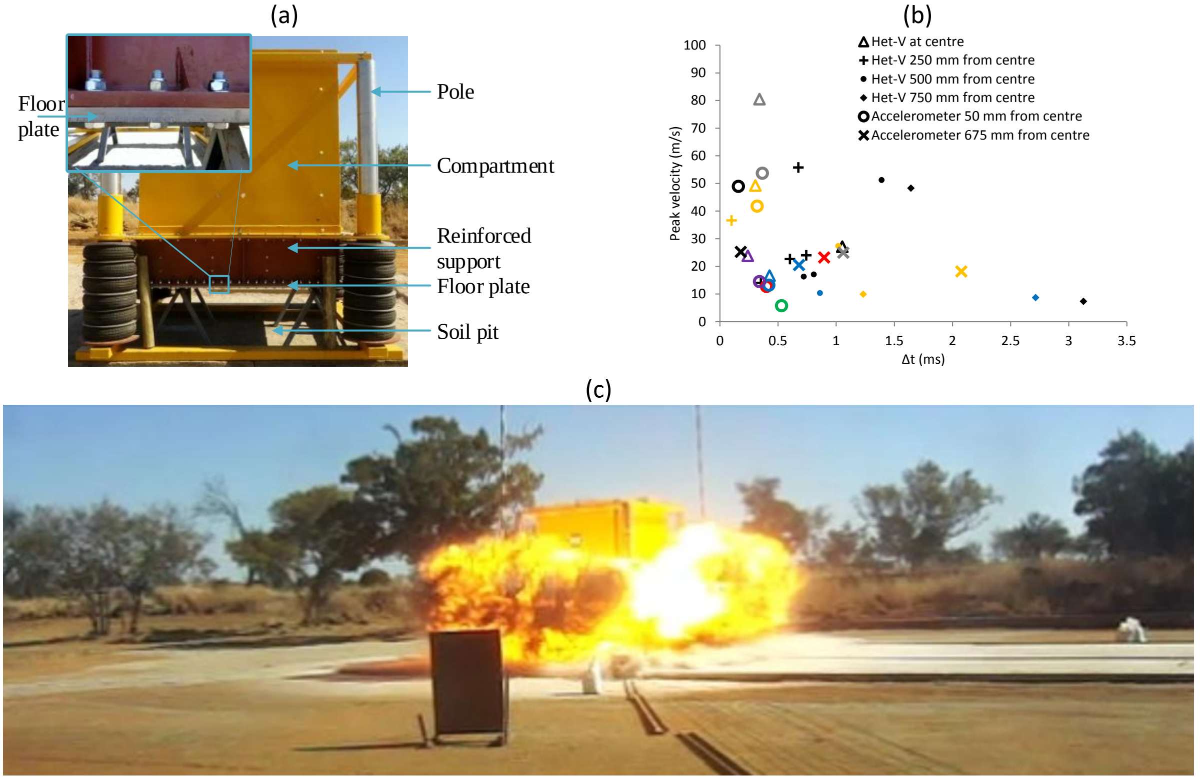


Figure 14: (a) Photograph of the vehicle surrogate, (b) peak velocity and time to peak velocity for all tests at different locations across the floor using both photonic Doppler velocimetry (PDV) and accelerometers to measure the floor response, and (c) snapshot of high-speed video captured during a 6kg TNT test.

Characterising floor behaviour during under vehicle blast

- This study determined the response of the floor of a surrogate vehicle when exposed to detonation charges between 1 and 6 kg TNT from underneath.
- Peak velocity ranged from 5.8 to 80.5 m/s and time to peak velocity ranged from 0.10 to 3.13 ms.
- These data should be taken into consideration when designing vehicle protection and traumatic injury simulators that aim at replicating the loading transferred by the floor to occupants during under-vehicle explosions.

Heterotopic Ossification: a review of current understanding, treatment and future.

Edwards DS, Kuhn KM, Potter BK, Forsberg JA. (2016)
Journal of Orthopaedic Trauma Vol. 30 No. 10 Supplement S27-30

Heterotopic Ossification (HO) is the formation of bone at extraskeletal sites. The incidence of HO in military amputees from recent operations in Iraq and Afghanistan has been reported to be as high as 65%. The condition poses problems to service members with and without amputation throughout early wound and soft tissue healing, rehabilitation and prosthetic fitting. HO may develop because of genetic diseases but more commonly it develops because of neurotrauma or musculoskeletal trauma or after surgery. HO after surgery is most associated with total hip arthroplasty. Posttraumatic HO is formed after trauma ranging from muscle sprains to open fractures of the long bones. The mechanism of formation is characterised by inflammation, myofibroblast proliferation and differentiation into chondroblasts or osteoblasts. Studies suggest that serum alkaline phosphatase levels increase during the early stages of HO formation, even before HO is clinically apparent, reaching a maximum at approximately 10 weeks.

The incidence of HO after civilian trauma ranges from 10-30% particularly spinal cord, brain, elbow and pelvic trauma. In contrast, HO is seen in over 60% of combat injured patients. The risk factors for developing HO in combat-wounded service personnel include blast mechanism of injury, injury severity score >16, multiple extremity injuries, increased number of surgical procedures and the use of negative-pressure wound therapy; suggesting that both systemic and local events play a critical role in the creation of conditions that contribute to pathologic bone formation.

In the civilian setting, nonsteroidal anti-inflammatory drugs and local radiotherapy are proven to prevent HO formation. There modalities however are generally medically contraindicated in the complex trauma patients or are logistically infeasible in a far-forward deployed environment. Early risk stratification to best identify wounds and patients at greatest risk is now possible via testing of local and systemic inflammatory biomarkers after injury.

Surgical excision and primary prophylaxis of HO in the polytrauma victim carry inherent risk. Therefore, much related research focuses on methods of primary prevention. Animals models have been developed that recreate the physiologic response to combat-related injuries in a reproducible manner; allowing for the evaluation of the effects of blast overpressure, bioburden and the cellular response resulting in HO.

HO: a substantial problem for combat related and civilian trauma

- HO affects up to 30% of civilian trauma patients and over 60% of combat injured patients.
- Safe, effective primary treatment for most indications does not exist.
- Lessons learned from recent conflicts continue to inform medical and surgical strategies when managing a symptomatic patient.
- Research is required and must focus on primary treatment at the cellular level.

Prophylaxis for blood-borne diseases during the London 7/7 mass casualty terrorist bombing: a review and the role of bioethics.

Edwards DS, Barnett-Vanes A, Narayan N, Patel HDL. (2016)
Journal of the Royal Army Medical Corps Vol. 162 Iss. 5

The suicide bombings in London on 7 July 2005 resulted in a mass casualty situation with over 50% of injured patients being treated at the Royal London Hospital. In some casualties, human biological material was found embedded in the soft tissue, originating from other casualties. This had the potential of placing individuals at risk of transmission of blood borne diseases and resulted in significant ethical scenarios surrounding patient management. This study reviews the literature of the 7/7 bombings, and suicide bombings reported globally, where biological implantations are noted. The aim was to examine the medicolegal issues arising during such an attack. In the immediate aftermath, the Metropolitan Police performed a forensic assessment of the scene using DNA mapping and identification. Projectiles in excess of 3cm^2 recovered from the scene were analysed. Material recovered during surgery was also analysed. Eight articles were identified relating to the subject of biological implantation from terrorist bombings. They revealed that during the course of the incident, 12 victims admitted to hospital were identified as having implanted human projectiles. Of the 12 patients, two died from their wounds and eight had biological material originating from the bombers. The remaining four had material that originated from casualties who had died on scene. All survivors were given Hepatitis B Virus (HBV) prophylaxis. Serum samples were taken for use at a later stage if required as per the recommendations of the Health Protection Agency (Figure 15). The one conscious patient received prophylaxis against HIV, as counselling and consent were possible. Current Public Health England/HPA guidance advises routine prophylactic treatment of HBV in those suffering from major penetrating injuries. The relative risk however of HIV or HBV transmission is yet to be fully assessed. Lack of understanding and limited guidance on ethical considerations regarding biological contamination in mass casualty bombings present a barrier to delivering high-quality emergency care.

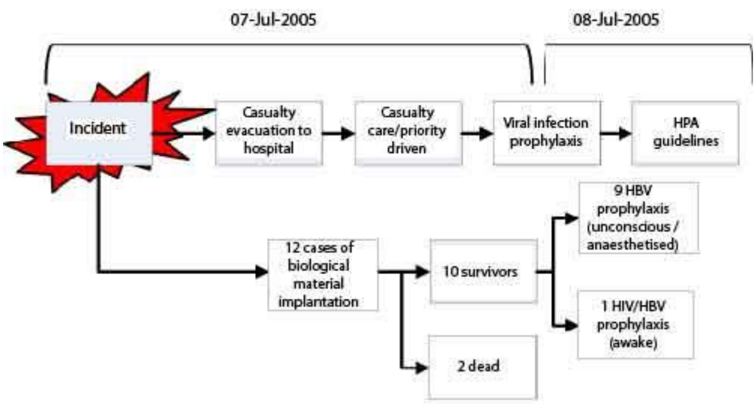


Figure 15: The sequence of events relating to blood-borne disease prophylaxis in cases of biological material implantation in the 7/7 bombings. (HBV - hepatitis B virus, HPA - Health Protection Agency).

What role does bioethics play in the treatment of blast injuries?

- Limited understanding exists on the infectiveness of contaminated human projectiles.
- This lack of understanding and limited guidance on ethical considerations regarding biological contamination in mass casualty bombings presents a barrier to delivering high-quality emergency care.
- Expert consultation is required in the areas of microbiology, trauma medicine and public health to examine the potential threat and define a standard framework for reporting explosive events.

In the Spotlight

In the Spotlight takes a look at significant related work published this year by researchers at key partner institutes who have either built on the output of the Centre, or have generated findings of significant use to its current research goals. Here we present work from Maj Neil Eisenstein, Trauma & Orthopaedic Surgery Trainee, currently undertaking a PhD at the School of Chemical Engineering, University of Birmingham. In addition, we show findings from a detailed study highlighting lessons learned from early rehabilitation of complex trauma at the Royal Centre for Defence Medicine.

Bedside, benchtop and bioengineering: physicochemical imaging techniques in biomineralization

Eisenstein NM, Cox SC, Williams RL, Stapley SA, Grover LM. (2016)
Advanced Healthcare Materials Vol. 5 Issue 5 pp 507-528

This study provides novel data using advanced techniques to analyse the physiochemical properties of mineralisation *in vitro* and *in vivo*. The techniques are presented in relation to human samples of combat related Heterotopic Ossification (HO); the rationale being that HO is an example of biomineralisation. Over 60% of amputees injured by improvised explosive devices in the Afghan conflict have developed HO[2] and as such, a renewed interest in the condition has developed. Pathological mineralisation in tissues can cause dysfunction in a broad array of organ systems. HO is an outlier due to the speed, volume and degree of hierarchical organisation it displays. Improving the understanding of such material properties will lead to new approaches in the prevention and treatment of the condition. This study highlights that if it could be shown that, in HO, calcium phosphate deposition and maturation into its final apatitic phase occurs through an alternative pathway to physiological ossification, then it could present possible therapeutic targets. The study also acknowledges the limitations in the physiochemical analysis of HO. The modalities described in this study are unlikely to advance our understanding of the upstream biology involved in the condition. Meaningful studies on the complex inflammation, signalling pathways and stem cell differentiation must continue in this field. CBIS is actively collaborating with the researchers who have produced this work so that our knowledge of HO is expanded rapidly in order to develop mitigation and treatment.

Lessons learned from early rehabilitation of complex trauma at the Royal Centre for Defence Medicine

Pope S, Vickerstaff AL, Wareham AP. (2016)
Journal of the Royal Army Medical Corps Jul 13 Epub 2016 https://www.ncbi.nlm.nih.gov/pubmed/27412360

UK service personnel sustaining major trauma on operations are evacuated to Queen Elizabeth Hospital Birmingham (QEHB), UK. Rehabilitation is delivered at QEHB until the patients are clinically appropriate for onward transfer to the Defence Medical Rehabilitation Centre (DMRC) Headley Court. During recent conflicts, advances in medical care along with improved personal protective equipment resulted in an increased number of survivors of complex trauma. The subsequent demands of these young, previously fit and active individuals created increased levels of expectation to achieve maximum functional gains at the earliest opportunity. A myriad of challenges for early rehabilitation was presented. This study reports those challenges and the advances that were made. It identifies lessons learned and the importance of documenting and communicating these. It recommends that early rehabilitation, pain management strategies and the development of validated outcome measures to assess effectiveness are seen as priorities for future research within the military rehabilitation of complex trauma.

[2] Forsberg JA, Pepek JM, Wagner S, Wilson K, Flint J, Andersen RC, Tadaki D, Gage FA, Stojadinovic A, Elster EA., (2009) Heterotopic Ossification in High-Energy Wartime Extremity Injuries: Prevalence and Risk Factors. The Journal of Bone & Joint Surgery Vol 91(5) pp 1084-1091

Associated Bioengineering Research

All academics associated with CBIS actively engage in associated research that leverages resources from the Centre, but also contributes to the Centre's mission. This bring resource benefits, but also contributes new ideas through the engagement of other academic staff and their research groups. All studies described here do not have the Royal British Legion as their primary source of funding, but are directly associated with the Centre.

Local mechanical factors of ectopic bone formation – Naomi Rosenberg

Funded by EPSRC.

The project expanded upon pre-existing bone remodelling algorithms in the literature in order to model the initiation and manifestation of heterotopic bone in the residual limbs of trans-femoral amputees. The novel algorithm introduced an extra factor that regulated the change in material density of tissues with respect to the proximity to the wound site and the current material stiffness. The remodelling was applied to three 2D residual stump geometries. Two characteristic types of heterotopic ossification had already been classified in the literature, Type 1 as a flame like spike and Type 2 as a beetle's shell like bulb. Three more classifications were identified in this study describing morphologies where: the heterotopic bone crawls up the medial side of the leg (Type 3), a convex formation of heterotopic bone forms proximally to the end of the residual femur (Type 4) and a distal bulb like formation that extends distally and medially (Type 5). Changing the loading through the residual femur could repeatedly result in either Type 1 or Type 2 formations of heterotopic bone in three different stump geometries. Reducing the stiffness of the skin layer repeatedly resulted in a Type 3 morphology for all models. Changing the location of the wound site to a more proximal medial or lateral location resulted in the Type 4 morphology. Type 5 was unseen and it is thought that this is due to the restricted available soft tissue in which remodelling could take place in the simulated models. This PhD student is supervised by Anthony Bull, CBIS Director, and provides core underlying analysis of the formation of HO. The study shows that characteristic morphologies of heterotopic bone can be produced by changing mechanical and biological parameters in the model; this opens the way for future mechanical interventions for mitigation and treatment.

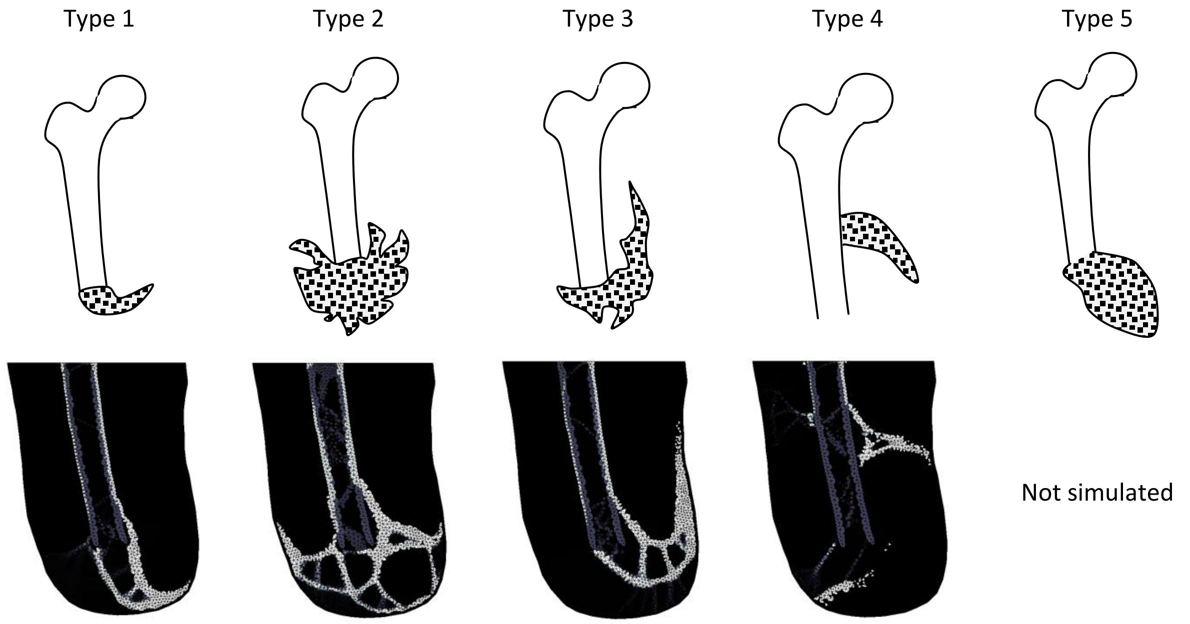


Figure 16: Top – Diagrammatic representations of type of HO.
Bottom – Simulated stiffness results (stiffest elements are white).

Understanding the musculoskeletal function of through- and above-knee amputees – David Henson

Funded by the Department of Bioengineering.

This project aims to analyse, understand and quantify amputee locomotion through the use of advanced musculoskeletal modelling techniques developed at Imperial College (Page 26). Ethical approval for this project has been granted by both the NHS and Imperial College London. Recruitment of the research cohort has begun and the first two subjects have been through the data collection protocols. These data are currently being processed prior to the recruitment of further subjects *en masse* in order that any required adjustments to protocol can be identified and implemented. Generation of the anatomical datasets has begun, with each limb of a through- or above-knee amputee requiring the identification and digitisation of over 100 muscle elements. These anatomical dataset will then be used in conjunction with the musculo-skeletal model of each limb, comprising of two biological segments—the pelvis and the thigh, and two prosthetic segments—the shank and the foot. Amputee muscle volumes and lines of action, in conjunction with measures of the electrical activity of muscles (EMG) recorded during amputee gait and maximum strength tests, will be used to create an amputee specific muscle model that will then be implemented in order to assess amputee muscular function during gait. Additional layers of detail will be added as the model progresses, with considerations to the prosthetic socket, the prosthetic knee damping system, the influence of the prosthetic foot characteristics and the influence of the patella to above knee amputee function, if it has been retained following amputation. The model will then be implemented and the following research questions addressed:

1. How can the anatomy of an amputee be artificially augmented in order to improve functional ability?
2. How can the central nervous system (CNS) recruitment of remaining muscles be improved in order to produce a more suitable force profile for functional ability?
3. What are the variations in kinetic and kinematic capacity between amputees, of varying functional ability, and able-bodied subjects? How can this information be used to improve amputee function?
4. What is the significance of remaining functional strength over other factors, such as joint control, stability or range of motion, or the ability to correctly position the centre of mass in determining functional outcome?
5. What are the factors that most influence the functional outcome of the amputee?
6. Can an in depth analysis of the amputee’s joint loading during movement, in conjunction with an understanding of the modified anatomy, provide insight into the co-morbid musculoskeletal conditions most likely to develop, such as osteoarthritis, and why?

Following this, intervention strategies can be engineered that offer improved functional ability for transfemoral amputees.

Biomechanics of the pelvis & sacroiliac joint – Thanyani Pandelani

Funded by the Department of Bioengineering and CSIR (South Africa).

This PhD project, currently in its second year, investigates injury patterns to the pelvis in under-vehicle blast as this is one of the body areas most susceptible to injury during this type of event. The protective ability of military vehicles is not validated for anything else but the nominal seated posture. Yet, it is more likely for an occupant of a military vehicle to be seated in a non-nominal posture during an explosion. This will result in a different loading mechanism and a different injury pattern to the pelvis. In addition, there is no metric in current standards for protection of the pelvis itself, yet battlefield data suggest that it is prone to injury. The specific question of the PhD is to address the vulnerability of the pelvis of a seated occupant in both nominal and non-nominal posture to injury in under -body blast, and to evaluate a protection mechanism.

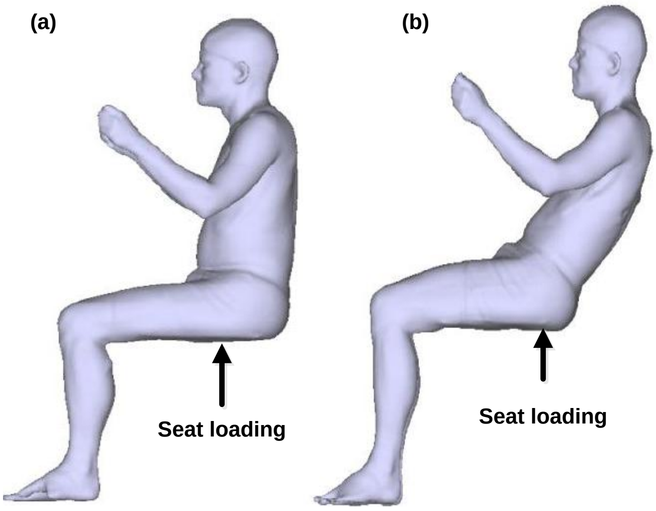


Figure 17: Loading of the pelvis from the seat in (a) Nominal and (b) non-nominal posture

Physical experimentation will replicate and detail the specific pelvis fracture pattern, and focus on the protection strategies for the seated occupant in both nominal and non–nominal posture. Experiments will be performed in house. The results from the experiment will be also be used to validate our existing finite element (FE) model of the pelvis. FE analysis, a powerful tool to investigate the mechanical environment within complicated geometries, allows examination of the mechanical responses of the bones and deep tissues (e.g., fat or muscle) of the pelvis resulting from external loading through the seat. The advantage of the FE model is its ability, after validation, to simulate multiple conditions and to be used as a design tool for protective equipment that could dissipate the injurious load being transferred the pelvis and the axial skeleton due to an explosion under the vehicle.

The beneficiaries of this work are not only CBIS in terms of building capacity and expertise, but all NATO and associated national agencies that are working on human vulnerability due to explosions. The ultimate beneficiary, of course, is the casualty, and society and economy through prevention of pelvic injury.

The new generation protective glove – Dr Angela Kedgley

Funded by SBRI / Innovate UK / MoD.

Injuries to the hand are of particular significance as they limit function pertinent to daily living. In Operation Iraqi Freedom and Operation Enduring Freedom the most common site of fracture in the upper extremity was the hand. Unfortunately, current standards for hand protection are not based on evidence from injury simulation. An ongoing collaborative project between Armourgel Ltd. and Angela Kedgley and Spyros Masouros from the Department of Bioengineering, funded by the Ministry of Defence by Innovate UK through SBRI, aims to establish injury risk, and then use this to design, fabricate and evaluate the next generation of protective gloves. This project is the first to determine the injury tolerance of the joints of the fingers and thumb, concluding that the criteria for protection against blunt trauma specified by the current European Standards were much lower than required to safety protect the joints. These data have been used in the design of a new glove with optimised functionality, incorporating targeted protection, while maintaining dexterity. A second round of funding has been awarded to the project that will see additional assessment of the injury tolerance of the human hand and further improvements to the glove design.

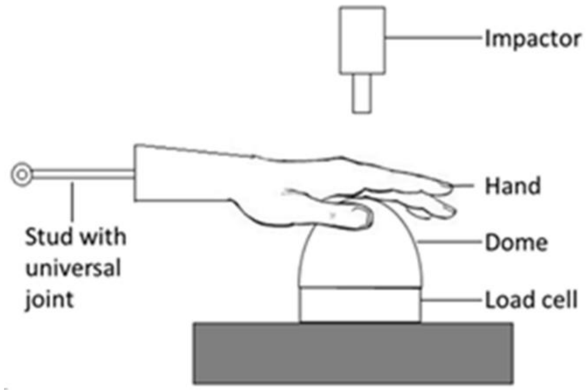


Figure 18: Schematic of the experimental set-up of the drop tower, viewed from the side. The injury tolerance of the small joints of the hand was determined by correlating injury severity due to the impact with the load measured by the load cell.

Imperial College
London

THE ROYAL BRITISH
LEGION

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