Imperial Blast
BIOMECHANICS & BIOPHYSICS

2011

# Imperial Blast current work

Imperial Blast Biomechanics & Biophysics

Imperial College London

December 2011

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**Imperial Blast Biomechanics & Biophysics**

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**London, December 2011**

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# Foreword

This second annual report of the Imperial Blast Biomechanics and Biophysics group is also its last in this guise. Since we were established nearly three years ago, it quickly became clear that the activities of the group were producing step changes in research capacity, through novel experimental models, and hot housing collaborations through jointly supervised projects across traditional scientific boundaries. However, the opportunities around this step change were not going to be fully realised unless there was a concomitant increase in resource and appropriate structures to facilitate, direct and manage this work. The Royal British Legion share this vision with Imperial Blast and I am delighted that this second annual report also heralds the establishment of The Royal British Legion Centre for Blast Injury Studies at Imperial College London.

This new Centre will be established along three main scientific themes and a series of research programmes in order to establish fundamental understanding of blast-induced molecular, cellular, tissue and organ dysfunction. Our aim is to improve the mitigation of injury and its rehabilitation, therefore reducing the welfare needs of wounded serving and ex-serving military personnel.

On behalf of Imperial Blast, I would like to thank all those who have supported us up to this point. Your support has enabled us to start delivering outputs that have the potential to provide significant benefits to military personnel. In this report we summarise the achievements of the past year and look forward to our new research programmes with the support of The Royal British Legion.

**Professor Anthony MJ Bull**

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

# Introduction

The conflicts in Iraq and Afghanistan have been epitomised by the insurgents' use of the Improvised Explosive Device (IEDs) and anti-vehicle (AV) mines against vehicle-borne security forces. These weapons, capable of causing multiple severely injured casualties in a single incident, pose the most prevalent single threat to Coalition troops operating in the region. Improvements in personal protection and medical care have resulted in increasing numbers of casualties surviving with complex lower limb injuries, often leading to long-term disability.

Imperial Blast is a collaborative whose efforts are uniquely able to address the disabling injuries of current and previous conflicts. The group is a careful balance of scientists, engineers and clinicians, from both the Ministry of Defence and academia, ensuring the right questions are asked, the difficult answers addressed, and the most appropriate technologies innovated, constantly aware of the Operational imperative to deliver tangible results in the shortest time possible.

Imperial Blast's approach to improving mitigation of, and recovery from, these injuries is to use a tri-modal scientific approach: clinical data analysis from the battlefields of Iraq and Afghanistan, Bioengineering experiments using physical and computational models of human tissue and Biophysical simulation of the effect of blast on living tissues are all brought to bear in a multidisciplinary environment with great effect. The following report summarises Imperial Blast's current work in each mode of endeavour since the last report in December 2010, and describes our future direction.

# Clinical focus

## Introduction

When an AV mine detonates, the blast wave from the explosion causes the release of a cone of super-heated gas and soil to impact the floor of the vehicle. This results in rapid bending of the floor, transmitting a large crushing force to the lower limb in contact with it (Figure 1).

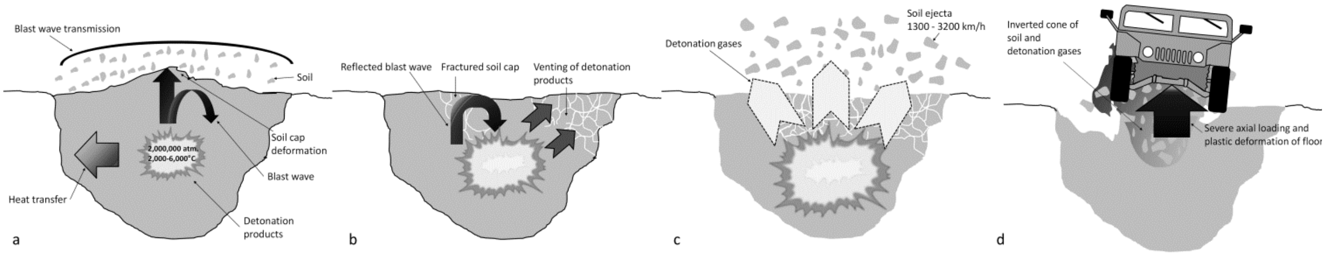


Figure 1: An AV mine blast. (*a*) Triggering of the mine results in an exothermic reaction and formation of a blast wave. (*b*) The blast wave is mainly reflected at the soil-interface and causes fracture of the soil cap. (*c*) The detonation products are vented through the fractured soil cap, resulting in the release of the soil ejecta. (*d*) The overall result is an inverted hollow cone of super-heated detonation gases surrounded by the soil ejecta. They both then act on the floor of the vehicle, resulting in injury to the occupants.

Typically, this produces injuries analogous to those in survivors from very high falls, but frequently far more severe. This injury pattern is of particular concern as it has been shown that patients with foot and ankle injuries have significantly greater disability compared to those without. These injuries are frequently so severe, that surgical reconstruction may not produce a good clinical outcome for these patients (Figure 2). The high physical demands placed upon Service Personnel are such that the long-term effects of these injuries are likely to play a significant role in their ability to return to full military duty.

One of the most significant deficits in vehicle explosion protection research has been the dearth of clinical information of in-vehicle blast casualties. Central to the success of any mitigation system is the ability to protect the soldier not only from lethal injuries, but also to reduce the possibility of long-term harm. In order to achieve this aim, a fundamental requirement is to define accurately the injury profile that is likely to result in disability in our young, highly active military population. Defence research organisations have often resorted to extrapolate injury criteria from automotive industry data. It is clearly apparent that military blast injuries are not similar to road-traffic accidents and the functional requirements of our population is likely to be significantly different.

One of the core features of the Imperial Blast group that will continue in the Centre for Blast Injury Studies is its focus on driving research priorities based upon contemporary battlefield injury data and long-term functional outcomes of military injury. This is facilitated by its strong partnership with the Royal Centre for Defence Medicine, and the integration of military surgeons with operational experience into this uniquely collaborative research group. This ensures that the group's research is entirely focused in understanding the injuries sustained, and protecting against the threats that might injure UK Service Personnel who are currently deployed on military operations. Here, we summarise Imperial Blast's recent work describing some of the disabling clinical effects of battlefield injuries. Unlike in most civilian type injury patterns, combat injuries frequently affect many body regions, resulting in the severely ill, multiply injured casualty. This is particularly the case in the casualty from blast.

Figure 2: A typical blast injury to the foot. This leg required amputation 2 years after injury.

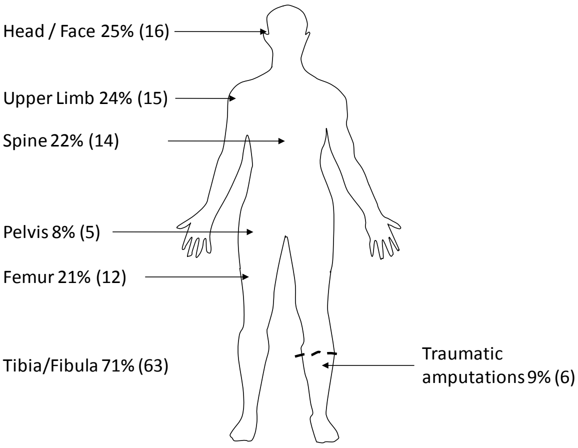


Figure 3: Injuries associated with foot and ankle military trauma

## Patients and Methods

We conducted a retrospective study of 63 casualties (89 lower limbs) injured in vehicle explosions between Jan 2006 to Dec 2008. All lower limb and associated injuries were recorded for each casualty. The injuries were scored clinically using the New Injury Severity Score (NISS). Specific to the foot and ankle injuries, these were also scored using the Abbreviated Injury Scale (AIS), and the Foot and Ankle Severity Scale (FASS).

## Results

Only 3 casualties suffered isolated injuries to the lower leg. Nearly a quarter had associated spinal injuries and head injuries (Figure 3). Overall these casualties had an average New Injury Severity Score (NISS) of 16 (15 denotes 'severely injured').

Twenty-six lower limbs (33%) injured from an under-vehicle explosion required amputation. Thirteen limbs were amputated at the field hospital, and 7 amputated when the patient returned to the UK. At a mean 18 months post injury, a further 6 casualties required amputation for chronic pain problems (Figure 4). When including the 6 legs that were traumatically amputated in the blast, it can be seen the significant burden of injury this places on our injured Service Personnel.

At 33 months post-injury, 75% of injured lower limbs had significant on-going clinical problems (Figure 4). This includes a high proportion of patients suffering from traumatic arthritis of the foot and ankle as well as those having problems from infection, impaired bone healing and chronic pain.

Given that the mean age of these casualties was 26 years these issues are likely to have a significant effect on their quality of life for several decades.

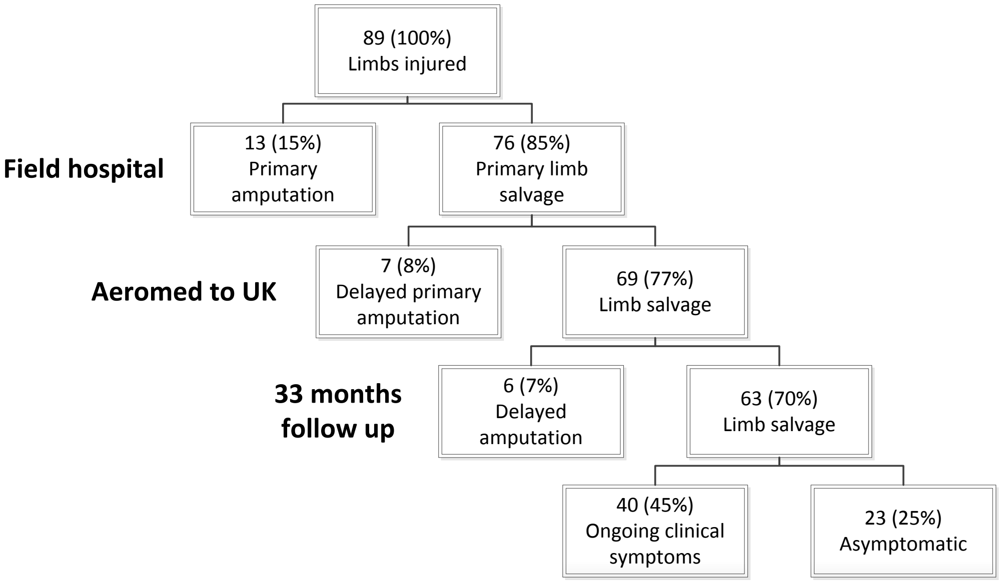


Figure 4: Casualties with lower limb injuries from Jan 06 to Dec 08 and 33 months follow up.

We correlated the clinical scores of the casualties (AIS and FASS) to the outcome of their injuries at 33 months. We found that both AIS and FASS were good predictors of amputation, but only FASS can predict ongoing clinical symptoms (Figure 5). The NATO standard for vehicle fitness sets the AIS (10% probability of an AIS ≥ 2 injury) as the requirement for fitness. The clinical data here demonstrates the AIS is not a good predictor of injury outcome for the lower limb.

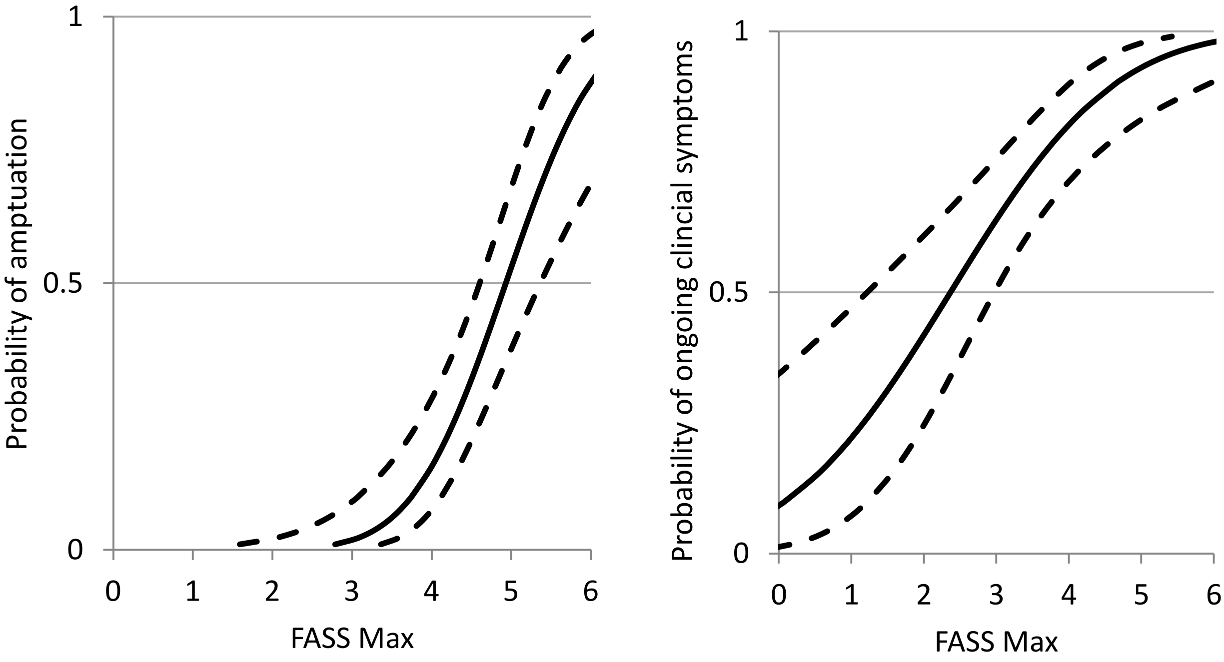


Figure 5: The Foot and Ankle Severity Scale (FASS) is a good predictor of the probability for amputation (left) and for ongoing clinical syndromes (right).

Almost 3 years after injury, only 9 (14%) of the casualties in this study were able to return to full military duty. Significantly, over 60% of those with a foot and ankle injury were only able to return in a sedentary role or were deemed unfit for any military service (Figure 6). Looking specifically at casualties with calcaneal fractures (30 casualties, 40 calcaneal fractures), we realised that the amputation rate was 45%, and that almost 80% of those patients were either unfit or returned to a sedentary role 33 months after injury.

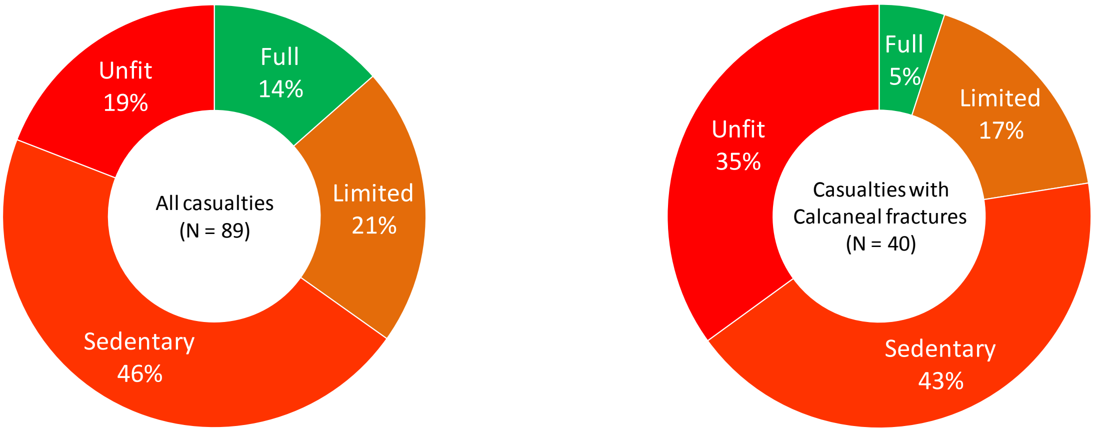


Figure 6: Occupational outcomes at 33 months.

## Conclusion and future work

Operational data demonstrate that foot and ankle injuries from AV mine blasts are associated with a poor clinical outcome. Given the nature of these injuries, the key in reducing the injury burden lays in primary prevention. By understanding the pattern of injury from blast, we are able to produce appropriate experimental tools to investigate and mitigate this devastating injury pattern.

We have collected and we are now analysing casualty data from Afghanistan, from Jan 2009 to date, and all fatalities since 2006. This wealth of data will allow us to identify further injury markers of poor prognosis, to advise our engineering work, and eventually propose better mitigation strategies.

# Engineering focus

## Introduction – Approach

Imperial Blast’s engineers use clinical data and expertise in order to design and develop experimental and computational tools that can be utilised to understand injury of the human lower limb, evaluate the mitigating capacity of existing technologies, and assess the potential of novel mitigation strategies (Figure 7).

## Experimental *vs*. Computational models

Experimental and computational models of human injury and of mitigation technologies are necessary in order to understand the physical mechanisms involved and to allow for developing new and improved evaluation criteria, techniques, materials and designs in a cost-efficient manner. Full scale experiments (e.g. the combat boot, the vehicle, the human leg under impact) give us an understanding of the whole ‘structure’ under fairly controlled, repeatable conditions; however, these are expensive, time consuming and labour intensive, albeit invaluable. Individual-component experiments (e.g. materials testing of combat boot components, of vehicle components, of soft and skeletal human components) are well controlled and repeatable, allowing us to understand component behaviour, and therefore to build accurate computational models able to predict the behaviour of the ‘structure’ based on the interaction of its components. Computational models that have been validated against relevant experiments allow for multiple virtual experiments to be conducted in a cost-efficient, repeatable, well-controlled manner. They allow us to alter inexpensively parameters related to geometry, materials, and environment and look at their effect on overall behaviour; hence, they allow us to experiment with novel designs and material combinations that could potentially result in novel, better mitigation strategies.

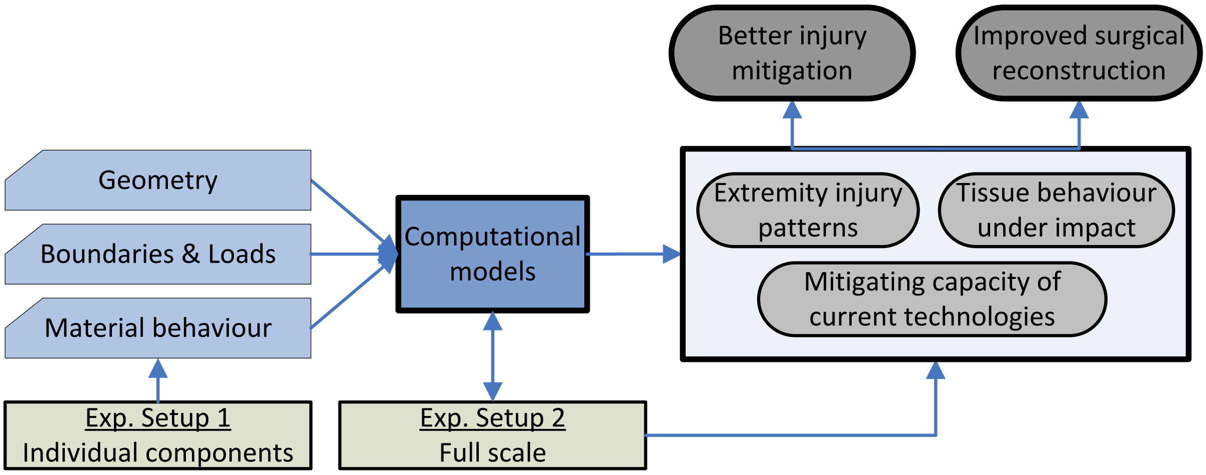


Figure 7: Biomechanical modelling approach of Imperial Blast.

## The Imperial Blast traumatic injury simulator (AnUBIS)

AnUBIS (Anti-vehicle Underbelly Blast Injury Simulator) is a pneumatically driven device able to accelerate a 42 kg plate up to velocities seen in the floor of vehicles when targeted by a mine (Figure 12). It is therefore capable of simulating the loading environment a vehicle occupant's leg will face. This capability is internationally unique. Combining multiple-sensor data, high speed video, and medical imaging, the conditions causing, and the mechanism and the severity of, the injury sustained by the leg can be quantified. This information is invaluable in order to inform and validate the computational models, to assess the effect of leg orientation and positioning on injury severity, to assess the biofidelity of surrogates, and to assess the effectiveness of full-scale mitigation technologies in reducing injury severity.

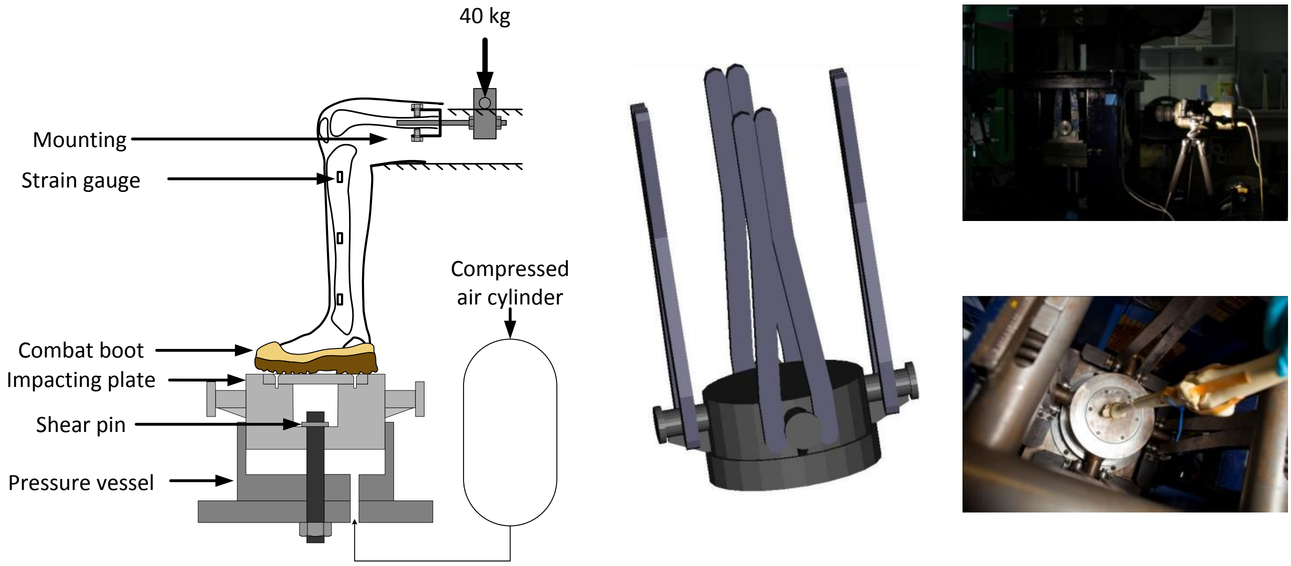


Figure 8: The Imperial Blast injury simulator (AnUBIS) is able to simulate the loading environment seen in AV-mine blasts.

Battlefield

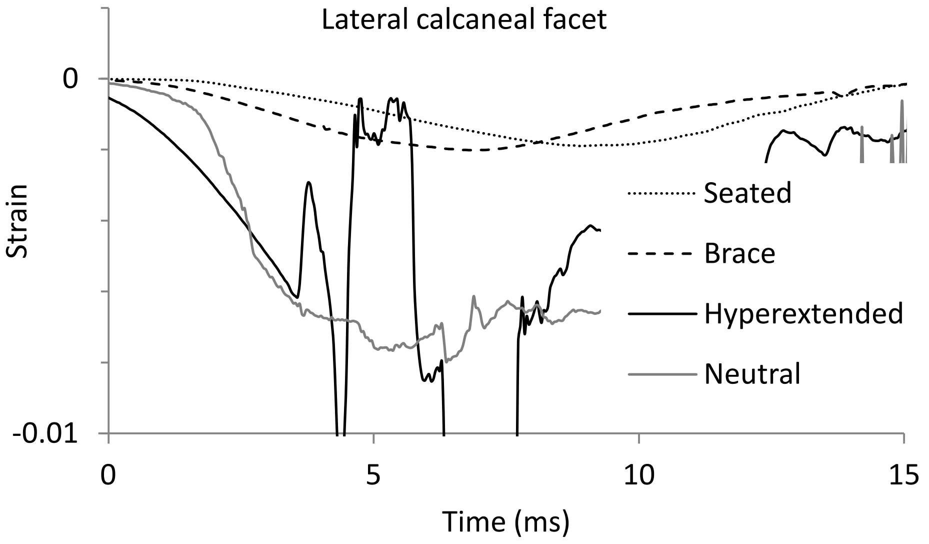
AnUBIS

Figure 9: Battlefield *vs.* AnUBIS injury outcome (CT reconstruction). Our traumatic injury simulator is recreating the foot and ankle injuries seen in the battlefield, and described in the *clinical focus*.

# The lower extremity

## AnUBIS experiments

Clinical and anecdotal evidence from the theatres of operation have led us to hypothesise that the seated posture, at which anthropometric test devices (ATDs or dummies) are placed in operational vehicle fitness tests, is the least severe of possible postures within a vehicle. We conducted tests in AnUBIS with cadaveric legs in postures that simulate the seated, standing (neutral), standing with a locked knee joint (hyperextended), and braced (knee joint flexed by 20°) postures. We quantified the results by clinically scoring the injuries sustained and by using strain gauges bonded directly on the skeleton. The standing postures sustained significantly more severe injuries compared to those at which the knee was bent (seated and braced; Figure 10).



| Posture | FASS |
|---|---|
| Seated | 1 |
| Brace | 1 |
| Neutral | 5 |
| Hyperextended | 5 |

Figure 10: Response of cadaveric legs when imparted with 500 J in AnUBIS. The strain response at the heel shows that the seated and braced occupant do not sustains any injury, whereas the standing occupants sustain fractures (sharp reduction and noise of signal thereafter). Clinical scoring of the outcome using the foot and ankle severity scale (FASS) shows that the standing postures sustain disabling injuries (FASS > 4).

## Computational modelling

A computational model of the lower extremity provides Imperial Blast with an internationally unique capability to conduct multiple virtual experiments in order to assess its behaviour under various impact conditions, simulating those seen in the theatres of operation. The geometry of a 50th percentile male's leg has been reconstructed utilising medical imaging and special software (Figure 11).

In order for the behaviour of a computational model to be biofidelic, accurate material models of its components' behaviour are mandatory. Whereas skeletal and soft tissue behaviour is fairly well understood in slow loading-rate conditions, this is not the case in higher loading-rate conditions, such as those seen in blast. Ligaments and bones are currently being tested by Imperial Blast across a range of loading rates in order to quantify their material behaviour (Figure 12).

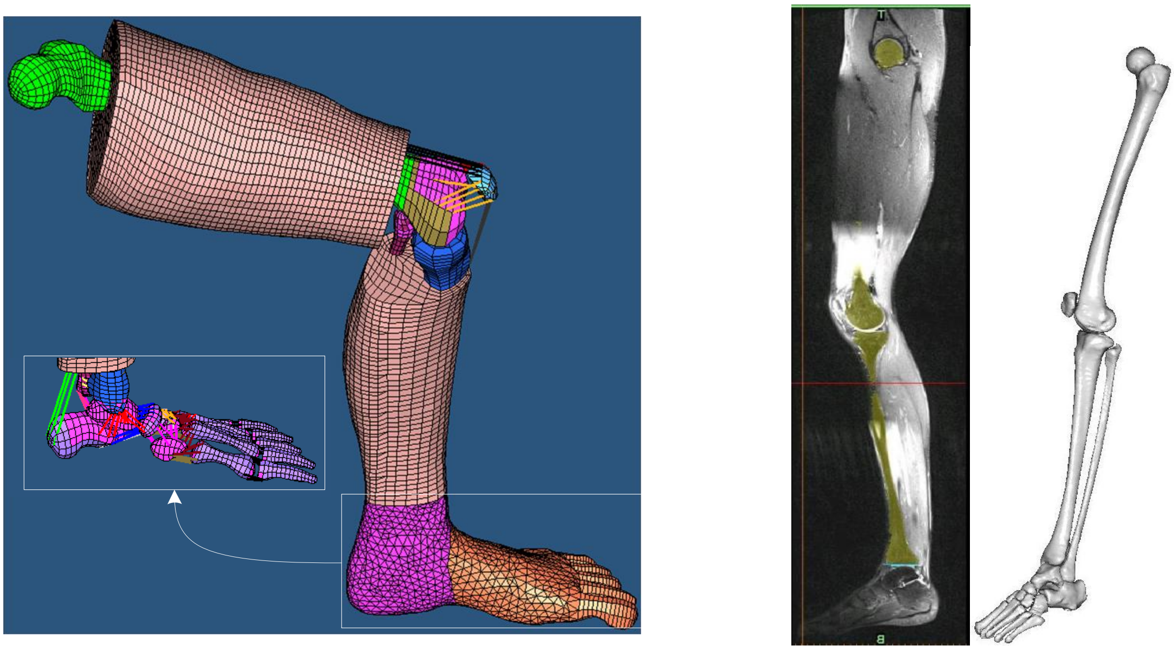


Figure 11: Computer model of the leg. It includes 22 individual bones, and 63 individual ligaments and tendons.

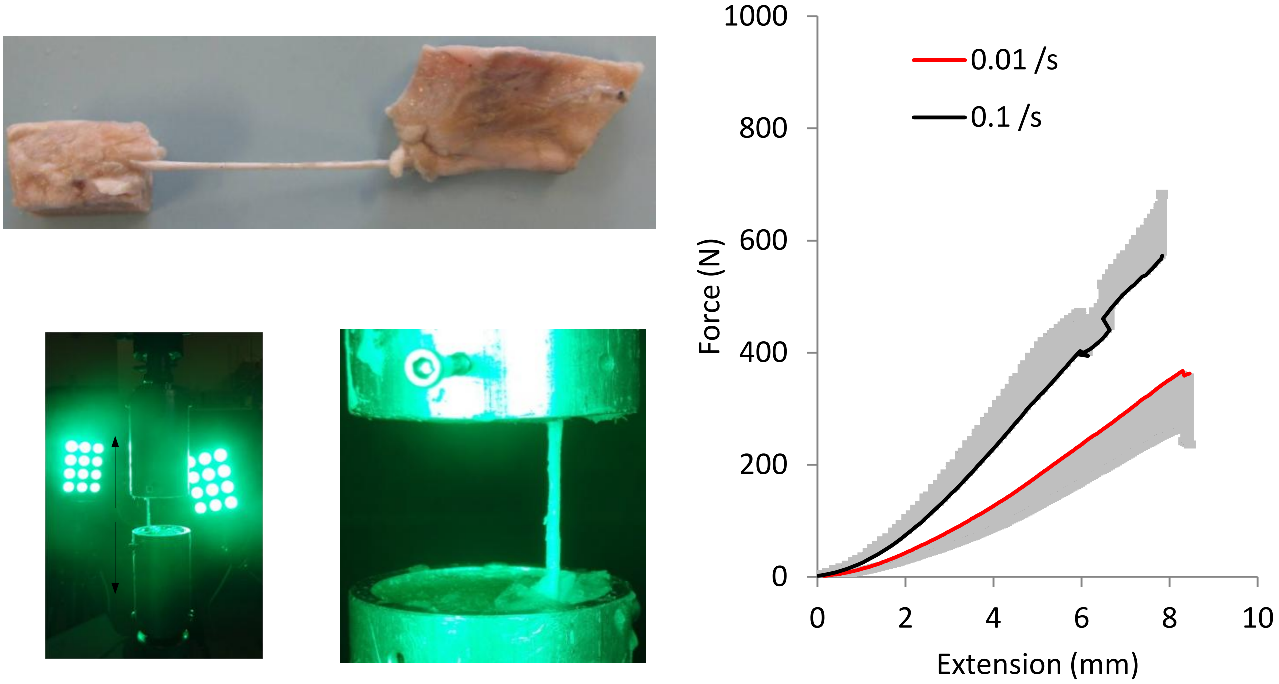


Figure 12: Knee ligaments are tested in tension in our labs. They appear sensitive to loading rate; specifically, as the rate increases, their stiffness (or resistance to lengthening) increases.

# Mitigation technologies

## Drop rig experiments

Combat boots currently deployed in the theatres of operation have been tested and modelled by Imperial Blast (Figure 13). The sole of the boots was impacted in a drop-weight test rig and its behaviour under impact was quantified. The individual components of the boots were also tested in order to quantify their material behaviour; this was used as an input into the computational models of the boot; the drop-weight experiment was simulated computationally with success. Now, the computational model of the boot can be combined with that of the leg to investigate the boot's role in extremity injury. Shock attenuating materials are currently being evaluated by Imperial Blast that can be used in future boot and vehicle designs.

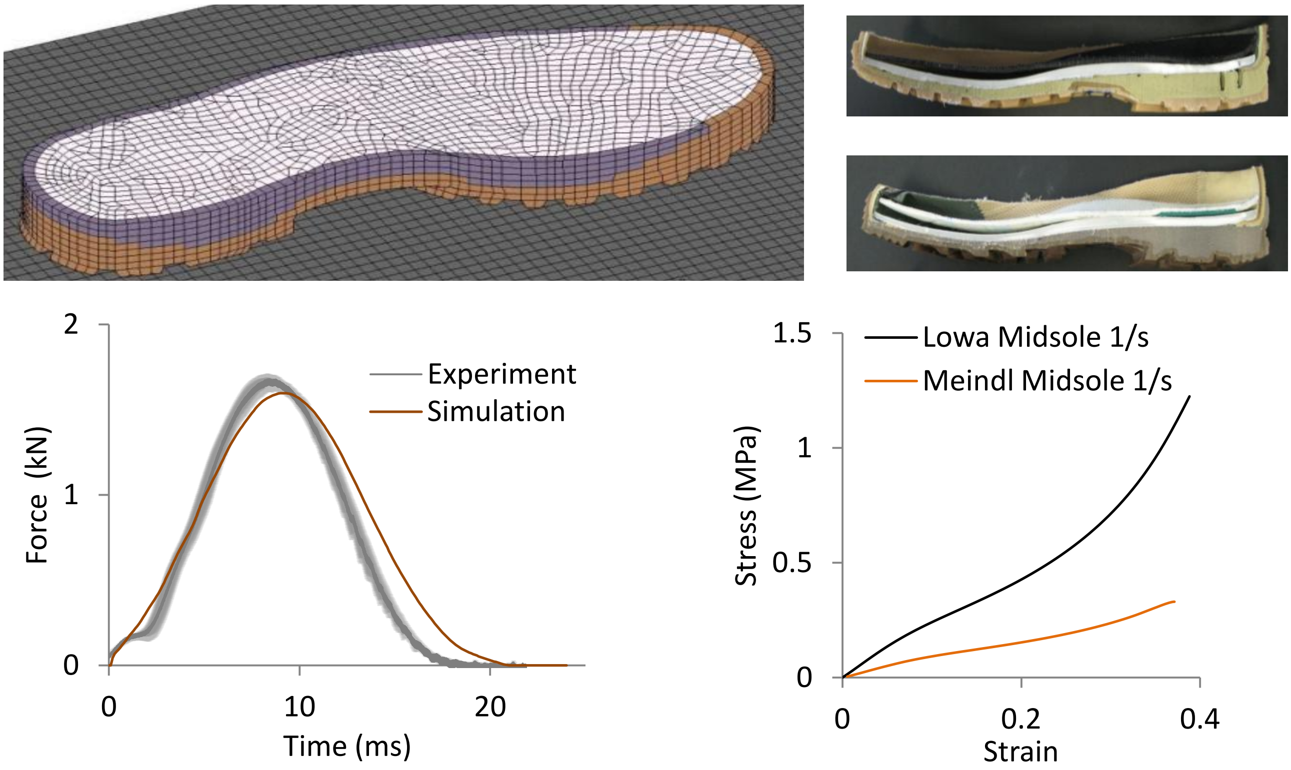


Figure 13: The sole of the combat boot was tested under impact and the experiment was modelled computationally. The individual material layers of the boots were tested to acquire their material and shock absorbing behaviour; this serves as an input to the computer models, but also allows for deep insight into differences in macroscopic behaviour (for example the drop rig test).

## AnUBIS experiments using ATDs

The sole of the combat boots was also tested under the ATD platform (Figure 14). Two types of dummy legs were used; the conventional leg (Hybrid-III) and the recently developed MIL-Lx. The latter has been tuned for axial impact, by incorporating a 10 cm long compliant element along the tibial shaft, and therefore is recognised as more biofidelic than the Hybrid-III. The sole of each combat boot was secured to the foot of the dummy leg and the leg was positioned at a seated posture on AnUBIS, as prescribed by the NATO standard for military vehicle fitness testing. Tests were carried out utilising the same threat as in the cadaveric experiments described earlier. Results show that the response between boots was significantly different under the Hybrid-III platform, but similar under the MIL-Lx platform.

It has to be noted that vehicle mitigation systems are being evaluated by most nations currently using the conventional, Hybrid-III leg. Our results demonstrate that the Hybrid-III leg is likely to be over-predicting the effects of mitigation systems on the resulting force transmitted through to the leg, and therefore the plausible risk of a disabling injury to the vehicle occupant. We are currently conducting a series of experimental and numerical simulations to elucidate the discrepancies between the ATDs currently used to assess the operational fitness of military vehicles and their correlation to the response of the human lower limb.

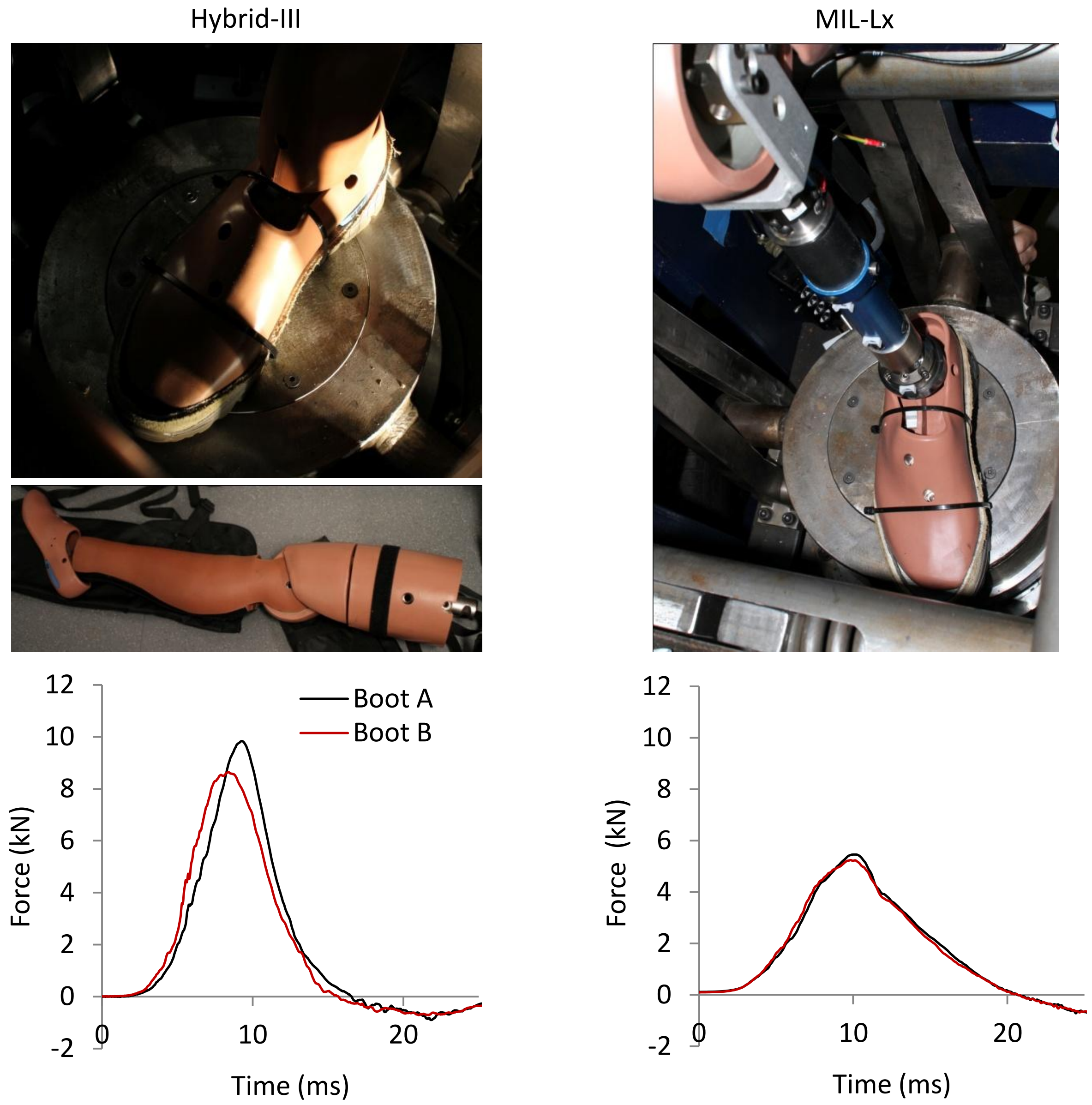


Figure 14: The combat boot under the Hybrid-III leg (left) and under the MIL-Lx leg (right). The MIL-Lx has been tuned for axial impact against cadaveric data, and therefore is recognised as more biofidelic than the Hybrid-III. The difference in response between boots was significant under the Hybrid-III platform, but minimal under the MIL-Lx platform.

# Biophysics focus

## Introduction

In current military conflicts, blast-related injuries, typically caused by the use of improvised explosive devices (IEDs), are often survivable. However, survival has offered clinicians and scientists a ‘window’ into the effect of high strain rate loading on biological systems, that until now would not have been survived. These injuries are invariably a result of high strain rate deformation of bone and soft tissues, resulting in fracture patterns, injury zones and tissue dysfunction uncommon in civilian injuries.

Blast injuries are characterised by multiple fractures and chronic pain, often leading to amputation. Specific complications that can develop in traumatised limbs in these war wounds include heterotopic ossification (HO; aberrant bone formation outside the skeletal tissue), and prolonged conduction delays in nerves to the extremities (peripheral nervous system). The fundamental physical properties that govern how live cells respond to external mechanical forces (e.g. blast stimuli) clearly underlie how subsequent cellular responses, such as damage and repair mechanisms, respond in both productive and non-productive manners (i.e. fracture healing compared to HO). Understanding the cellular effects high intensity compression waves induce in human tissues is a critical step towards developing improved therapies for patients suffering from blast injuries.

## Methods and materials

### Chamber design

We have developed a system for applying high intensity compression waves to cell cultures using a modified split Hopkinson pressure bar system, equipped with a biocompatible chamber that permits recovery of samples for further cellular and molecular analyses. Different chamber designs have been tested and the optimal configuration that insures minimal volume losses and allows the measurement of the hoop strain and consequently of the inner radial stress developed during compression experiments has been chosen (Figure 15). However, this current design still requires further optimisation.

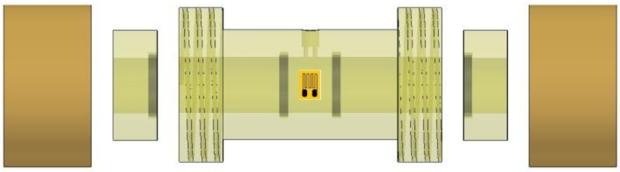


Figure 15: Chamber design.

The chamber is composed of three parts: a main body in polycarbonate (centre object) with bore holes where liquid is inserted using a syringe; two polycarbonate discs with O-ring seals; and two brass screw caps that hold the components together and align the chamber on steel SHPB systems bars.

## Biological samples

Mouse mesenchymal stem cells (MSCs) were chosen as the first biological samples to be tested under compression because they are hypothesized to play a key role in wound healing processes including the development of HO, are feasible to be grown in culture and can survive in suspension for several hours. MSCs were cultured from the bone marrow of Balb/c mice by seeding in tissue culture flasks and expanding to near-confluence (70%-90%) at 37°C, 5.0% CO2. MSCs were *passaged* (repeatedly transferred from one culture vessel to a new one to enable continuous cell growth) in order to achieve high cell densities before being used in compression experiments.

# Results

## Chamber mechanical response

The chamber performance was initially tested on the SHPB system by inserting 1 mL of water and then firing the striker bar at an impact velocity of 8.5 m/s. One-, two- and three-wave analyses showed that equilibrium was reached approximately 20 µs after impact (Figure 16). This result validates the use of classical SHPB theory to determine the axial stress in the sample.

The stress time history of all the experiments performed on cell cultures were recorded and analyzed with a Matlab routine specifically developed for SHPB experiments.  Average curves are shown in Figure 17 for two experiments performed in triplicate using cell suspensions ($10^6$ cells/mL) in compression studies with impact velocities of approximately 8.5 m/s or 9.5 m/s. The maximum error recorded between different curves obtained with the same experimental conditions is given wtihin approximately 5% of the peak pressure value.

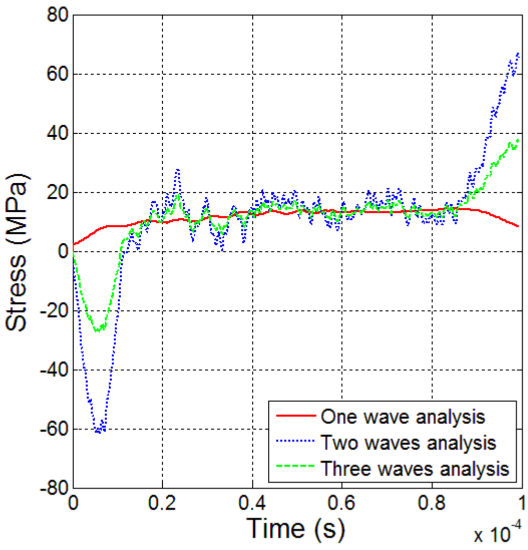


Figure 16: Stress equilibrium in the sample.

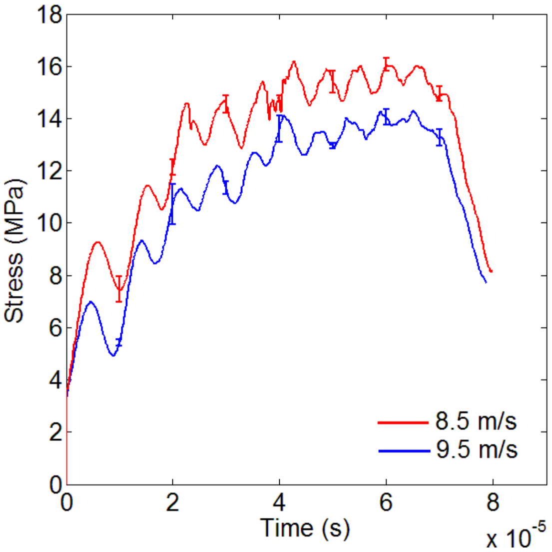


Figure 17: Stress time response for cell suspensions.

## Cell damage

Analysis of cell count data showed a significant reduction in number of cells recovered after compression compared to cell suspensions that have been introduced in the chamber but not subjected to a pressure stimulus (Figure 18). In order to understand the loss of cells, the supernatant (liquid lying above the sediment of cells) was collected after centrifugation from all the samples and the DNA content was measured. Higher levels of DNA content in the compressed supernatants suggests cell lysis (Figure 19).

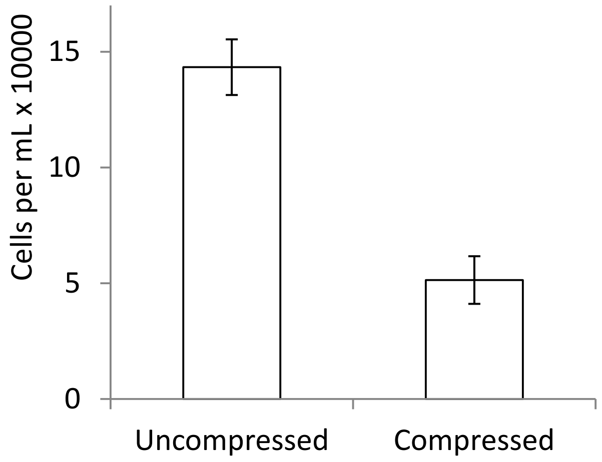


Figure 18: Cell count of recovered samples.

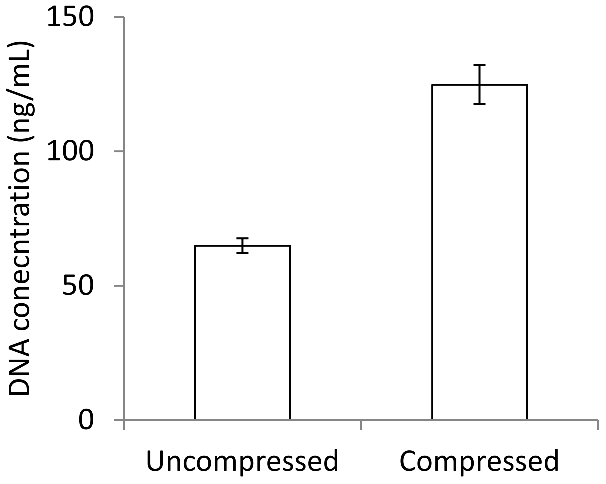


Figure 19: DNA content in supernatants collected after compression experiments.

Cell viability was assessed via flow cytometry using the LIVE/DEAD® Viability/Cyto-toxicity Kit (Invitrogen, L3224). Comparison of the FACS data in Figure 20 shows little difference between the control and uncompressed cells, and demonstrates that these samples are predominately composed of live cells. In comparison, compressed cells show an increase in populations of dead and possibly damaged cells.

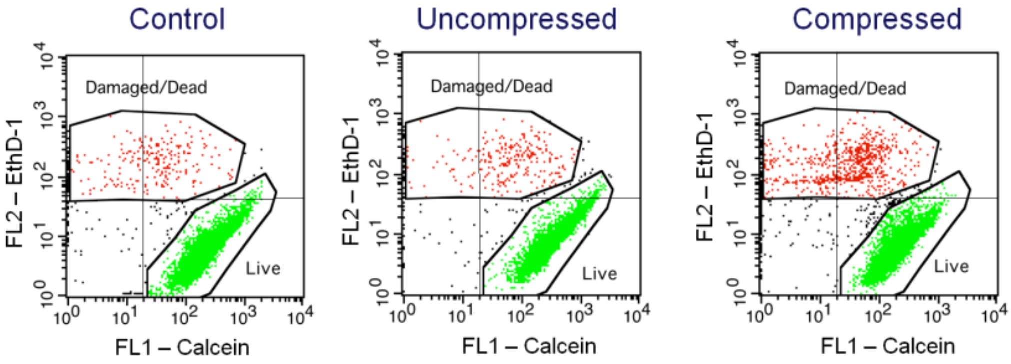


Figure 20: FACS analyses of cell viability. Two regions can be distinguished on each graph indicating populations of live cells or dead and/or damaged cells. In the compressed sample an increase in number of red dots indicates that the damaged/dead population has increased following the pressure stimulus.

## Conclusions and future work

A confinement chamber was designed to subject live biological samples to dynamic pressure events resembling blast injury conditions. Our initial results indicate that significant number of cells in the mouse MSC cultures are killed or possibly damaged by the high compression wave produced in our current SHPB experimental setup. The reduction in cell counts of cultures following compression suggests that lysis, possibly related to damage of the cell membrane, is occurring. Future work will include biochemical and cellular studies to identify specific mechanisms responsible for compression wave-induced cell death and damage. Also, supernatant collected after compression will be tested for the presence of damage markers (as DAMPs) using FACS or ELISA based assays. Control and compressed cells will be cultured in the collected supernatant and viability and proliferation will be measured at different time points. The experimental setup used to compress cell suspensions will be also used to test animal tissue. The mechanical properties of the tissue will be recorded and histological examination will be performed to give an insight on the nature of morphological damage *in vivo*.

# External collaboration

## Imperial Blast, and its place at Imperial College London

Since its foundation in 1907, Imperial has enjoyed a reputation for excellence in research and technological innovation that today attracts the most talented minds of international quality, consistently ranking the University within the top 10 in the world (top 5 in Europe). Indeed, 14 Nobel Prize winners and two Fields Medal winners are amongst Imperial's alumni and current faculty.

Imperial's unique approach to successfully answering real-world issues is founded through fostering multidisciplinary working internally, and encouraging wide collaboration externally. In doing so, it remains committed to exploring the interface between science, engineering, medicine and business, delivering practical solutions that improve the quality of life.

Imperial College London's multidisciplinary collaborations and partnerships now include internationally recognised initiatives to address Operational and National Security issues. It is for this reason that Imperial is the natural home for the Imperial Blast research group and its successor, The Royal British Legion Centre for Blast Injury Studies at Imperial College London, founded to address the scientific issues related to the signature injuries of recent conflicts by leveraging the expertise developed through this network.

Unlike other academic institutions, Imperial College London has a clear vision to make a demonstrable economic and social impact through the translation of its research into practice both in the UK and abroad. Imperial Blast and now its successor, the Centre for Blast Injury Studies, is uniquely placed to achieve these aims by collaboration with professionals from many different world-leading departments within the College. The multidisciplinary work has already engaged internationally renowned experts in the fields of Shock Physics, Mechanical Engineering, Civil & Environmental Engineering, Histopathology, Biology, Biochemistry and Aeronautics.

To date, Imperial Blast has benefited from the engagement of a number of different organisations, including the Royal Centre for Defence Medicine (RCDM), the Defence Science and Technology Laboratory (Dstl), and the Fracture and Shock Physics Group, Cavendish Laboratory, University of Cambridge.

## The Royal Centre for Defence Medicine

The Royal Centre for Defence Medicine in Birmingham has unrivalled experience in the clinical management of combat injury. Integral to RCDM's multidisciplinary approach to the management of these injuries is its ability to translate novel and emerging basic research findings into rigorous applied scientific advances in medical and surgical care. The volume of injury from recent and current conflicts managed by RCDM has enabled the development of powerful wound prediction and outcome tools that inform the clinical relevance of all basic research endeavours.

## Defence Science and Technology Laboratory

The Defence Science and Technology Laboratory orchestrates the Science and Technology (S&T) sector's response to the Ministry of Defence's current and future needs. Dstl interfaces with industry and academia to maximise the impact of S&T for defence and security requirements, and in doing so, delivers battle-winning technologies. Dstl project-manage a number of large defence contracts, often requiring the outsourcing of work to academic and industry expert partners.

## The Fracture and Shock Physics group. Cavendish Laboratory, University of Cambridge

The Fracture and Shock Physics group is part of the wider Surfaces, Microstructure and Fracture theme. The group has researched for over 60 years in the area of explosives research and has pioneered the use of high-speed diagnostics. A wide variety of loading techniques are used to produce controlled stress pulses which are used to simulate real world events. Nanosecond imaging and high-resolution optical techniques as well as pressure systems operating at half a million atmospheres are used. The overall aim of this research is to develop the physical understanding of material response at extremes. The applications of this research are in areas such as safety, design, mining and quarrying, ballistics, blast protection. The materials of interest are wide-ranging e.g. metals, polymers, explosives, sand, soils etc.

The interaction with Imperial Blast and the Institute of Shock Physics has allowed this group to bring its expertise to bear on biological materials, which has resulted in an extremely productive cross-fertilisation of research ideas and understanding.

# Communication of the work

## Media focus

This year, a team of enthusiastic and gifted science communication Masters students were embedded in Imperial Blast. Their remit was to communicate the work of Imperial Blast to an audience that might not ordinarily access our scientific publications, and explore some of the more complex issues related to undertaking research and development in the Defence sector. David Robertson, Elizabeth Crouch, Anna Perman and Benjamin Good attended group meetings, observed experiments and produced written and audiovisual material that were viewed by thousands of people over a 6 month period on the Public Library of Science, or PLOS blog. The written and audiovisual materials can be found at http://blogs.plos.org/thestudentblog/author/ikteam/.

The work was also highlighted in the Soldier Magazine recently, with a feature spread article on the work associated with boot design (August 2011, Vol 67/8, pp:37-39).

http://www.soldiermagazine.co.uk/archives/magazine/aug11/aug11feature4.htm

## Survivability and Resilience Network, Institute of Biomedical Engineering

In order to both communicate its work, and enhance engagement with its vision, Imperial Blast has most recently developed a Technology Network. The mission of the Survivability and Resilience Technology Network (SRTN) is to improve health and increase quality of life after ballistic, blast and flash related trauma. This is done by a multidisciplinary approach to improving injury mitigation, advancing treatment, and optimizing rehabilitation and recovery. Central to the SRTN is The Royal British Legion Centre for Blast Injury Studies at Imperial College London, which will build upon the College’s history of Defence and Securities related research, most recently demonstrated by the Imperial Blast research initiative.

The SRTN brings together a critical mass of scientists and clinicians, engineers and innovators, all of whom will be affiliates of the new Centre, to drive the development of technologies and services which can rapidly be deployed in support of those who defend our infrastructure and national interests. These developments will focus on; increased protection of personnel, enhancing the performance of personnel in challenging and austere environments, and improving recovery and rehabilitation of those injured by blast or ballistic events.

The SRTN can be accessed through the website:

http://www3.imperial.ac.uk/biomedeng/networks/survivabilityandresiliencetechnologynetwork

## Invited lectures

Clasper JC. *Blasted bones.* Trauma care conference, May 2011.

Bull AMJ. *Plenary Keynote Lecture.* Combined Services Orthopaedic Society (CSOS) meeting, May 2011.

Masouros SD. *Mechanical behaviour of the lower limb under high loading rates.* Micromechanics, Engineering Department, University of Cambridge, October 2011.

Clasper JC and Bull AMJ. *Crew compartment and seating. Human injuries due to under-vehicle IEDs.* Vehicle Survivability. November 2011.

Ramasamy A. *Battlefield injuries: military injuries and disability.* Royal College of Surgeons England, December 2011.

## Awards

Philip Fulford Memorial Prize awarded to TJ Bonner for the paper. *The early management of unstable pelvic ring fractures: the effect of circumferential binder position on diastasis reduction*. Combined Services Orthopaedic Society (CSOS) meeting, May 2011.

Best trainee prize awarded to A Ramasamy for the paper. *The modern 'deck-slap' injury: calcaneal fractures from under-vehicle explosions.* Combined Services Orthopaedic Society (CSOS) meeting, May 2011.

## Recent publications

Below is a list of recent documents produced by Imperial Blast. These documents and those from previous years that are open access can be found at http://www.imperialblast.org.uk/current-work/.

### Publications in peer-reviewed journals

Newell N, Masouros SD, Pullen AD, Bull AMJ. *The comparative behaviour of two combat boots under impact.* Injury Prevention. 2011; i*n press*

Ramasamy A, Hill AM, Gibb I, Philip R, Bull AMJ, Clasper JC. *AIS is not a predictor of poor clinical outcome in lower limb blast injuries: implications for blast research*. Journal of Orthopaedic Trauma. 2011; *accepted for publication.*

Ramasamy A, Hill AM, Gibb I, Philip R, Bull AMJ, Clasper JC. *The deck-slap injury: outcomes from calcaneal blast injuries*. Journal of Trauma. 2011; *in press*.

Brown KA, Bo C, Masouros SD, Ramasamy A, Newell N, Bonner TJ, Balzer J, Hill AM, Clasper JC, Bull AMJ, Proud WG. *Prospects for studying how high intensity compression waves cause damage in human blast injuries*. Bulletin of the American Physical Society: Topical group on Shock Compression of Condensed Matter. 2011.

Bo C, Balzer J, Brown KA, Walley SM, Proud WG. *Development of a chamber to investigate high-intensity compression waves upon live cell cultures*. The European Physical Journal: Applied Physics. 2011; 55: 31201.

Ramasamy A, Hill AM, Masouros SD, Gordon F, Clasper JC, Bull AMJ. *The blast mitigating effect of mine-resistant vehicles: historical lessons in vehicle design*. Accident Analysis and Prevention. 2011; 43(5): 1878-86.

Ramasamy A, Hill AM, Masouros SD, Gibb I, Bull AMJ, Clasper JC. *Environmental influence on blast-related fracture patterns: a forensic biomechanical approach*. Journal of the Royal Society: Interface. 2011; 8(58): 689-98.

Ramasamy A, Newell N, Masouros SD, Hill AM, Proud WG, Brown KA, Bull AMJ, Clasper JC. *Extremity injuries from improvised explosive devices: current research and future focus*. Philosophical Transactions of the Royal Society Part B: Biological Sciences, 2011; 366: 160-170.

## Manuscripts submitted for publication in peer-reviewed journals

Ramasamy A, Hill AM, Masouros SD, Gibb I, Philip R, Bull AMJ, Clasper JC. *The re-emergence of solid blast injury: outcomes from foot and ankle blast injury.* Journal of Bone and Joint Surgery – Am.

Masouros SD, Newell N, Ramasamy A, Bonner TJ, West ATJ, Hill AM, Clasper JC, Bull AMJ. *Design of a traumatic injury simulator for assessing lower limb response to high loading rates.* Annals of Biomedical Engineering.

## Government reports

IB/DSTL/010411/01. *Understanding injury of the lower limb in vehicle IED*.

## Policy submission

The Royal British Legion: Evidence Submission to Dr Murrison, Prosthetics Review, March 2011. http://www.armedforceshealthpartnership.org.uk/media/1633619/drmurrisonprostheticsreview.pdf

## Science communication

Hill, AM. Explosive Injuries POSTnote, Parliamentary Office for Science and Technology, November 2011

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