Department of Defense

Science and Technology Efforts and Programs Relating to the

Prevention, Mitigation, and Treatment of Blast Injuries

FY12 Report to the Executive Agent

DoD Blast Injury Research Program Coordinating Office

US Army Medical Research and Materiel Command

Executive Summary

Medical research programs of the Department of Defense (DoD) are working to significantly advance the DoD's capability to prevent, mitigate, and treat blast injuries. Since its inception in 2006, the Blast Injury Research Program has played a key role in coordinating research programs and developing partnerships within the DoD, nationwide, and internationally. This Report to the Executive Agent highlights the activities undertaken in fiscal year 2012 by the Blast Injury Research Program, DoD and other federal agencies, academia, industry, and international partners to advance the state of the science and solve difficult blast injury problems.

Among the key initiatives described in this report are:

- The Military Health System Blast Injury Prevention Standards Recommendation Process that supports weapon system health hazard assessments, combat platform occupant survivability assessments, and protection system development.
- The Joint Trauma Analysis and Prevention of Injury in Combat Program is a DoD partnership that assists with analyzing data on combat injury events to identify actionable information that can be used by vehicle program managers, warfighter protective equipment developers, and US Army Training and Doctrine Command capability managers to improve the DoD's capability to prevent and mitigate blast injuries.
- A new North Atlantic Treaty Organization Human Factors and Medicine Panel activity formed to promote international collaboration and standardization to address critical research needs such as physics-based modeling of animals and humans in relevant blast environments, blast exposure monitoring methods and metrics, and standardized protocols for blast injury research.

Among the key research accomplishments reported are:

- Researchers at the University of Nebraska at Lincoln demonstrated a maxillofacial protection system added to a combat helmet that not only provides increased ballistic and blunt impact protection to the face but also mitigates blast waves. The US Army Product Manager Soldier Protective Equipment conducted testing and subsequently released 100 of the maxillofacial systems to a combat unit to conduct training and to utilize when deployed.
- Stratatech Corporation, with funding from a Military Infectious Diseases Research Program applied research award, developed a human skin substitute for use in burn and trauma patients that was awarded US Food and Drug Administration orphan drug status in 2012. Efforts are ongoing to incorporate antimicrobial agents into the material to prevent infection.
- Researchers at the US Army Institute of Surgical Research, in collaboration with the Naval Medical Research Center, have found that the induction of mild traumatic brain injury in a rat following a moderate level of blast overpressure can also induce injury of the rat's ocular pathway. This is the first study to identify apoptosis (a cell death process initiated in response to stress or physical or biochemical damage) in ocular tissues following exposure to sublethal blast overpressure.

- The Office of Naval Research supported research to develop a new helmet that combines polymers with DuPont Kevlar® to mitigate shock from a blast exposure without sacrificing ballistic protection. The Naval Surface Warfare Center, Carderock Division is doing testing on full-sized manikins. The Massachusetts Institute of Technology is analyzing the results using biofidelic large-scale computations of manikins, with promising preliminary findings of reduced blast effects on the brain.
- The US Army Tank Automotive Research, Development and Engineering Center Ground Systems Survivability organization has developed unique decoupled underbody integration concepts and underbody integration standards that will enable improved vehicle survivability and occupant protection. The new underbody concepts will attenuate the highly accelerative forces experienced during blast.
- Researchers from the Walter Reed National Military Medical Center (WRNMMC), in collaboration with the DoD Hearing Center of Excellence and the National Center for Rehabilitative Auditory Research, made significant progress in the development of clinical assessment tools for evaluating central auditory processing disorders in blast-exposed military personnel. Their rapid screening test for blast-related central auditory processing disorders has been adopted for use in the clinics at the WRNMMC and the National Intrepid Center of Excellence.
- The Defense Advanced Research Projects Agency Wound Stasis System (WSS) program performer, Arsenal Medical, Inc., has developed a self-expanding, polyurethane-based polymer foam to control bleeding in the abdominal cavity. The WSS foam would be used by medics to treat noncompressible truncal hemorrhage, a leading cause of survivable fatalities, to reduce blood loss and stabilize patients for transport. Researchers observed an increase in survival rate from 8% to 73% at three hours in a swine model using the WSS.
- Researchers at the US Army Institute of Surgical Research are evaluating the effects of bacterial biofilms on wound healing in vitro and in vivo. Results in animal models suggest that the local delivery of D-amino acids (a biofilm dispersal agent) reduces the biofilm and can enhance the activity of systemic antibiotics against bacteria within a biofilm. Such therapies could improve wound healing and reduce complications.
- The Armed Forces Institute of Regenerative Medicine is evaluating composite tissue transplantation for wounded warriors with severe disfigurement and dysfunction. Scientists at Brigham and Women's Hospital have successfully performed four face transplants, and the patients are experiencing return of sensation and motor function to the transplanted tissue. Researchers at the University of Pittsburgh Medical Center are investigating the use of structural fat grafting to improve craniofacial appearance after trauma.
- Researchers at the University of Texas at Dallas are using a haptic (i.e., tactile feedback) virtual reality training environment with continuous electroencephalogram (EEG) monitoring to train young people to improve their response time and decision making for visuomotor tasks. These training paradigms are being used to improve visuomotor performance in normal individuals, improve performance in patients who were impaired in these functions, and measure these brain state changes through EEG markers.

The significant research accomplishments and initiatives highlighted in this report illustrate what can be done when information is shared, when expertise and knowledge are leveraged, and when medical research programs are coordinated. These are the outcomes that Congress intended when it directed the Secretary of Defense to establish a coordinated DoD Blast Injury Research Program.

Foreword from the Director

Current overseas operations, worldwide terrorist bombings, and the use of improvised explosive devices continue to demonstrate the impact of conventional and low-tech blast weapons in causing catastrophic injuries and death. Technologies and procedures to prevent, treat, and mitigate the effects of these weapons have made tremendous advances in the last year. New maxillofacial protection is helping influence the design of the next generation Integrated Head Protection System, and protective undergarments are reducing urogenital injuries. Advances in hemorrhage control and damage control surgery have helped reduce the percentage of our warfighters dying from "survivable" wounds to a record low. New techniques are improving the diagnosis of traumatic brain injury. Advances in rehabilitation procedures, including improved prosthetics and success with reconstructive surgery, have enabled more of our injured Service men and women to return to duty or to productive civilian life.

In spite of these advances, many challenges remain. Among these are understanding the mechanisms of blast-related brain injuries, assessing the environmental toxicology of blast, continuing to improve hemorrhage control and resuscitation, evaluating limb salvage as an alternative to amputation, providing access to historical blast injury research data, and identifying blast injury prevention standards to support the continued development and testing of safe weapons and effective combat platform occupant and individual protection systems.

This report describes the efforts of the Department of Defense (DoD) Blast Injury Research Program to address the entire spectrum of blast injury challenges during fiscal year 2012 and highlights significant accomplishments during this period. These accomplishments illustrate what can be realized when diverse medical, operational, and materiel development communities within the DoD eliminate traditional mission stove pipes, break down communication barriers, establish effective partnerships, and leverage the vast biomedical research expertise that resides not only within the DoD but in other federal agencies, academia, and industry, both within the United States and in other nations.

Information sharing encourages collaboration, prevents duplication of effort, and fulfills the underlying objective of the congressionally mandated DoD Blast Injury Research Program. This compilation of initiatives and accomplishments informs the Executive Agent and shares information with the many organizations that comprise the DoD Blast Injury Research Program.

I am pleased to present this report to the Executive Agent on behalf of the vast network of dedicated professionals who are the foundation of the DoD Blast Injury Research Program.

Michael J. Leggieri, Jr.
Director, DoD Blast Injury Research
Program Coordinating Office

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Chapter 1

Introduction

“There can be no greater legacy than saving lives.”

Leon E. Panetta, Secretary of Defense, October 29, 2012

Operations in Afghanistan and Iraq, worldwide terrorist bombings, the advent of novel explosives, and the growing use of improvised explosive devices (IEDs) have resulted in a significant number of blast-related casualties. In 2006, Congress directed the Office of the Secretary of Defense (OSD) to designate an Executive Agent (EA) to be responsible for coordinating and managing the medical research efforts and programs of the Department of Defense (DoD) relating to the prevention, mitigation, and treatment of blast injuries. In response to this direction, the DoD-issued DoD Directive (DoDD) 6025.21E, “Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries,” on July 5, 2006 (see Appendix B) that designated the Secretary of the Army (SecArmy) as the DoD EA and assigned program oversight to the Assistant Secretary of Defense for Research and Engineering (ASD[R&E]). As shown in **Figure 1-1**, the Secretary of the Army delegated authority and assigned responsibility to execute EA responsibilities to the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA[ALT]), and the ASA(ALT) further delegated authority and assigned program responsibility to the Commander, US Army Medical Command (USAMEDCOM). The DoDD also assigned additional responsibilities within the DoD as shown in **Figure 1-2**.

The Blast Injury Research Program Coordinating Office (PCO) was subsequently established within USAMEDCOM at the US Army Medical Research and Materiel Command (USAMRMC), Fort Detrick, Maryland, to assist the EA in coordinating and managing blast injury-related DoD medical research efforts and programs. The PCO coordinates and manages relevant DoD medical research efforts and programs, identifies blast injury knowledge gaps, shapes medical research programs to fill identified gaps, facilitates collaboration among diverse communities both within and outside of the DoD, as shown in **Figure 1-3**, and widely disseminates blast injury research information. The activities of the PCO are further described in Chapter 2.

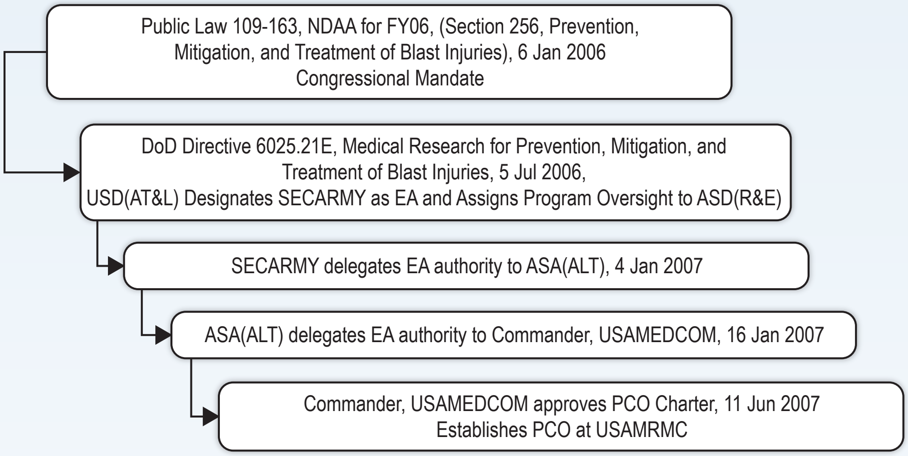


Figure 1-1. Assignment of EA Authority*

* The DoDD also established the Armed Services Biomedical Research Evaluation and Management (ASBREM) Committee to facilitate coordination and prevent unnecessary duplication of effort within DoD biomedical research and development (R&D) and associated enabling research areas.

Responsibilities and Functions	ASD(R&E) (ASBREM Chair)	ASD(HA) (ASBREM Co-Chair)	SECARMY (EA)	SECNAV & SECAF	USUHS	CJCS	USSOC	JIEDDO
Oversee EA	X							
Approve Blast Injury Research Programs	X							
Ensure New Technology is Transitioned to DoD Components	X							
Assist in Requirements Development and Needs Assessment	X	X		X			X	X
Approve MHS Blast Injury Prevention, Mitigation, and Treatment Standards		X						
Ensure MHS Information Systems Support the EA		X						
Share Blast Injury Research Information as Broadly as Possible			X					
Program, Budget, and Execute ASD (R&E)-Approved Programs			X					
Support Joint Database for Improving Protection Systems (via JTAPIC)			X					X
Recommend MHS Blast Injury Prevention, Mitigation and Treatment Standards			X					
Appoint ASBREM Reps			X	X	X	X	X	X
Coordinate all Blast-Injury Efforts and Requirements Through the EA				X	X	X	X	X

Figure 1-2. Program Responsibilities and Functions from DoDD 6025.21E

SECNAV=Secretary of the Navy; SECAF=Secretary of the Air Force; USUHS=Uniformed Services University of the Health Sciences; CJCS=Chairman of the Joint Chiefs of Staff; USSOC=United States Special Operations Command; JIEDDO=Joint Improvised Explosive Device Defeat Organization; MHS=Military Health System; JTAPIC=Joint Trauma Analysis and Prevention of Injury in Combat

Figure 1-3. Breadth of the PCO's Coordinating Responsibilities

CG=Commanding General; DARPA=Defense Advanced Research Projects Agency; JNLWD=Joint Non-Lethal Weapons Directorate; NATO=North Atlantic Treaty Organization; TSWG=Technical Support Working Group

Defining Blast Injuries

The term "blast injury" includes the entire spectrum of injuries that can result from exposure to an explosion. The DoD Blast Injury Research Program uses the Taxonomy of Injuries from Explosive Devices as defined in DoDD 6025.21E (**Figure 1-4**) to characterize such injuries.

This taxonomy assigns blast injuries to five categories—Primary, Secondary, Tertiary, Quaternary, and Quinary—based on the mechanism of injury. Primary blast injuries result from the high pressures created by the blast itself. These high pressures, known as blast overpressure, can crush the body and cause internal injuries. Primary blast injuries are the only category of blast injuries that are unique to blast. Secondary blast injuries result when the strong blast winds behind the pressure front propel fragments and debris against the body and cause blunt force and penetrating injuries. Tertiary blast injuries result from the strong winds and pressure gradients that can accelerate the body and cause the same types of blunt force injuries that would occur in a car crash, a fall, or a building collapse. Quaternary blast injuries are the result of other explosive products (such as heat and light) and exposure to toxins from fuels, metals, and gases that can cause burns, blindness, and inhalation injuries. Finally, quinary blast injuries refer to the clinical consequences of "post-detonation environmental contaminants," including bacteria, radiation (dirty bombs), and tissue reactions to fuel and metals.

Key Program Features

The Blast Injury Research Program is addressing critical medical research gaps for blast-

Unique to Blast

PRIMARY

- Blast lung
- Eardrum rupture and middle ear
- Abdominal hemorrhage and perforation
- Eye rupture
- Non-impact, blast-induced mild traumatic brain injury

SECONDARY

- Penetrating ballistic (fragmentation) or blunt injuries
- Eye penetration

TERTIARY

- Fracture and traumatic amputation
- Closed and open brain injury
- Blunt injuries
- Crush injuries

QUATERNARY

- Burns
- Injury or incapacitation from inhaled toxic fire gases

QUINARY

- Illnesses, injuries, or diseases caused by chemical, biological, or radiological substances (e.g., "dirty bombs")

Figure 1-4. Types of Blast Injuries per DoDD 6025.21E related injuries. The program is leveraging new extramural blast injury research partnerships with DoD medical research laboratories to achieve a cutting-edge approach to solving blast injury problems. Medical research products include medical standards for enhanced personal protective equipment (PPE). The program is addressing the concept of "reset" for warfighters in redeployment, ensuring return-to-duty readiness (or healthy return to civilian life for citizen Soldiers, Sailors, Airmen, and Marines). One of the program's major areas of focus is the improvement of battlefield medical treatment capabilities to mitigate neurotrauma and hemorrhage. Finally, the program is modernizing military medical research by bringing technology advances and new research concepts into DoD programs (**Figure 1-5**).

Key Research Topics

The Blast Injury Research Program is focusing on filling key gaps in the blast injury knowledge base. Key research topics by program area include:

Injury Prevention

Injury Prevention mitigates the risk of blast injuries by providing medically based design guidelines and performance standards for individual and combat platform occupant protection systems; comprehensive injury surveillance systems that link injury, operational, and protection system performance data; tools to identify individual susceptibility to injury; and individual resilience training to prevent or mitigate injuries.

Acute Treatment

Acute Treatment mitigates injury by providing immediate and definitive treatment across the spectrum of blast-related injuries through improved diagnostic tools, health care provider training, wound care, and medical treatment outcomes analysis.

Reset

Reset mitigates disability by providing a biomedically based performance assessment capability for return-to-duty in redeployment and following injury, restoring full performance capabilities in redeployed individuals, and restoring function and ability to seriously injured Service members with prosthetics and regenerative medicine. The term "reset" acknowledges a concept that extends beyond rehabilitation to include all activities necessary to return injured Service members to duty or to productive civilian life.

Figure 1-5. Blast Injury Research Program Areas

Funding

Medical research within the DoD is supported through multiple organizations and funding sources. The main types of funding are the President's Budget (PB) and Congressional Special Interest (CSI) appropriations. PB funds are traditionally referred to as "core" and represent the DoD/President's planned budget. A key aspect of DoD core research programs is that research is "requirements driven." The research is focused on improving or filling a gap in the force's capabilities in preventing and treating injury and restoring function. CSI funds are adjustments to the PB that reflect congressional priorities. CSI funds are often directed by Congress to topics that relate to the DoD core programs, for example, traumatic brain injury (TBI) and orthopedic trauma. Through participation by key members of core research programs and clinical/research subject matter experts (SMEs) in vision setting, program announcement topic decisions, and proposal funding selection, the DoD core programs leverage CSI funding toward filling capability gaps. Blast injury research is funded by both PB and CSI funds.

Some of the key CSI-funded programs are listed in **Table 1-1** along with their focus areas for fiscal year (FY) 2012. These programs, funded through the Defense Health Program (DHP), are managed by the USAMRMC. Core funding programs of the DoD Services and agencies are discussed as follows.

Table 1-1. FY12 Focus of CSI Programs with Blast Injury-Related Research

CSI Program	Program Focus
Psychological Health and Traumatic Brain Injury Research Program	Focused on identifying and characterizing mechanisms of TBI-related neurodegenerative diseases, including chronic traumatic encephalopathy, with emphasis on those mechanisms of injury that may be amenable to targeted therapy approaches, as well as biomarkers that would identify mechanistic targets of therapeutic approaches. The program has also established the Chronic Effects of Neurotrauma Consortium, which will be dedicated to developing a comprehensive understanding of the chronic sequelae associated with neurotrauma (see Table 1-2).
Peer Reviewed Orthopaedic Research Program	Supports military-relevant orthopedic research. Areas of emphasis include the improvement of moisture management and residual limb skin care at the prosthetic socket interface, improvement of the rate of nerve regeneration, strategies to inhibit neuromas at surgical/amputation sites, the treatment of segmental bone injury in weight-bearing locations, treatment and prevention of heterotopic ossification, mitigation of the musculoskeletal and physiologic effects of reduced mobility for polytrauma patients, short-term and long-term outcomes in limb salvage populations, and prevention or treatment of posttraumatic joint stiffness and contracture (in the ankle, knee, and/or elbow).
Spinal Cord Injury Research Program	Concentrates on areas related to the management of acute spinal cord injury (pre-hospital, en route care, and early hospital management) and the prevention of pressure ulcers; as well as areas related to chronic spinal cord injury such as autonomic dysfunction, bowel dysfunction, neuropathic pain and sensory dysfunction, respiratory dysfunction, sleep-disordered breathing, and ventilation management.
Vision Research Program	Addresses capability deficiencies and gaps in vision rehabilitation strategies and quality-of-life measures, vision restoration, and mitigation and treatment of traumatic injuries, war-related injuries, and diseases to ocular structures and the visual system. It also addresses mitigation and treatment of visual dysfunction associated with TBI, ocular and visual systems diagnostic capabilities and assessment strategies, and warfighter vision readiness and enhancement related to refractive surgery.
Peer Reviewed Medical Research Program	While many of the topics are not blast-related, FY12 solicitations for research and clinical trials included topics of composite tissue transplantation, nanomedicine for drug delivery science, posttraumatic osteoarthritis, and tinnitus.

More information on these programs can be found at http://cdmrp.army.mil/ and for the Vision Research Program at http://www.tatrc.org/.

Service and Agency Programs

The Army, Navy, Air Force, and DARPA each have ongoing core research programs related to blast injury. These programs sponsor research within DoD laboratories and clinical centers as well as externally within academia and industry. The research includes the areas of injury surveillance, combat casualty care (CCC), wound infections, military operational medicine (MOM) (prevention and return-to-duty), and clinical and rehabilitative medicine (CRM). In FY10, the Office of the Assistant Secretary of Defense for Health Affairs established a core R&D program to enhance the related medical R&D programs of the Services and DARPA, accelerating the transition of medical technologies into products and knowledge into new standards of care. The current emphasis of that program is on the Secretary of Defense's stated priorities of posttraumatic stress disorder (PTSD), TBI, prosthetics, restoration of eye sight and advancing eye care, and other conditions directly relevant to battlefield injuries, and other ailments that affect both Service members and their families. Coordination of Service and agency programs is achieved through joint oversight and management committee structures, such as Joint Technology Coordinating Groups under the ASBREM Committee and Joint Program Committees (JPCs) under the DHP.

The DoD has also established key research institutes and clinical Centers of Excellence (CoEs) to advance solutions to blast injury-related problems. One example, depicted in **Table 1-2**, is the Chronic Effects of Neurotrauma Consortium (CENC) that will address chronic consequences (lasting 3 months or more) that occur in some individuals having experienced a TBI, including mild TBI (mTBI)/concussion. Another is the Armed Forces Institute of Regenerative Medicine (AFIRM), managed by the USAMRMC, which is focused on innovative technologies and approaches to harness the

Table 1-2. Chronic Effects of Neurotrauma Consortium

CENC **http://cdmrp.army.mil/funding/pa/12phtbicenc_pa.pdf**
FY12 CSI and US Department of Veterans Affairs (VA) funding is being used to establish the CENC to address critical needs in the understanding and treatment of chronic effects of neurotrauma and TBI including mTBI (over the lifespan of the patient). These issues include: identification and characterization of the anatomic, molecular, and physiological mechanisms; evaluation of how comorbidities are associated with and exacerbated by neurotrauma; and appropriate treatment and rehabilitative strategies. The CENC framework will consist of a coordinating center collaborating with multiple research sites. The CENC will leverage existing infrastructure and collaborations. It is expected that each research site will consist of collaborating partners, namely, VA and/or DoD Treatment Facilities and one or more strongly relevant non-federal entities, including academic institutions and industry (e.g., private clinics and rehabilitation centers). The Consortium will include core facilities at member organizations, such as informatics, biorepository, imaging, and statistical laboratories, to enable Consortium studies. The period of performance will be a maximum of 5 years and funding will be supplied by DoD, with VA providing additional funding for VA sites.
CENC Objectives
The CENC will focus on establishing a comprehensive understanding of the chronic sequelae associated with neurotrauma, primarily focused on mTBI/concussion as defined by the DoD/VA. Key priorities are the development of diagnostics, including a broad range of biomarkers, and novel treatment and rehabilitative strategies to improve the long-term health and well-being of Service members and veterans. Included are comorbidities such as psychological, neurological (including memory, seizure, autonomic dysfunction, and sleep disorders), sensory deficits (including visual, auditory, and vestibular dysfunction), movement disorders, pain (including headache), and cognitive and neuro-endocrine deficits. The CENC will coordinate research activities, specimen repository/usage, and analyses. The emphasis is on basic and preclinical studies to address the anatomic, molecular, and physiological mechanisms issues while clinical studies will be emphasized to address the comorbidities issues. The specific Consortium objectives are to: • Establish the association (onset, prevalence, and severity) of the chronic effects of mTBI and common comorbidities. • Determine whether there is a causative effect of chronic mTBI/concussion on neurodegenerative disease and other comorbidities. • Identify diagnostic and prognostic indicators of neurodegenerative disease and other comorbidities associated with mTBI/concussion. • Develop and advance methods to treat and rehabilitate chronic neurodegenerative disease and comorbid effects of mTBI/concussion.

body's repair and regenerative mechanisms to treat severe injuries (http://www.afirm.mil/). USAMRMC recently consolidated oversight of the many regenerative medicine projects it manages under a single office—the Regenerative and Restorative Medicine Management Team—to improve management and coordination in this advancing research field. This team currently has execution oversight for 22 clinical trials and 140 individual grants, including the AFIRM, Biomedical Translational Initiative, and Small Business Innovation Research (SBIR)-funded projects.

Numerous DoD CoEs focused on improving the clinical care capabilities have been created in response to congressional requirements within National Defense Authorization Acts. These centers look for ways to improve care via new and updated clinical practice guidelines, policy recommendations, understanding injury and outcome trends, and informing research sponsors as to the needs and requirements of the clinical communities. CoEs that focus on blast injury include the Defense Centers of Excellence (DCoE) for Psychological Health and Traumatic Brain Injury, the Extremity Trauma and Amputation Center of Excellence, the Hearing Center of Excellence, the Pain Center of Excellence/Defense and Veterans Center for

Table 1-3. Pain Center of Excellence/Defense and Veterans Center for Integrative Pain Management

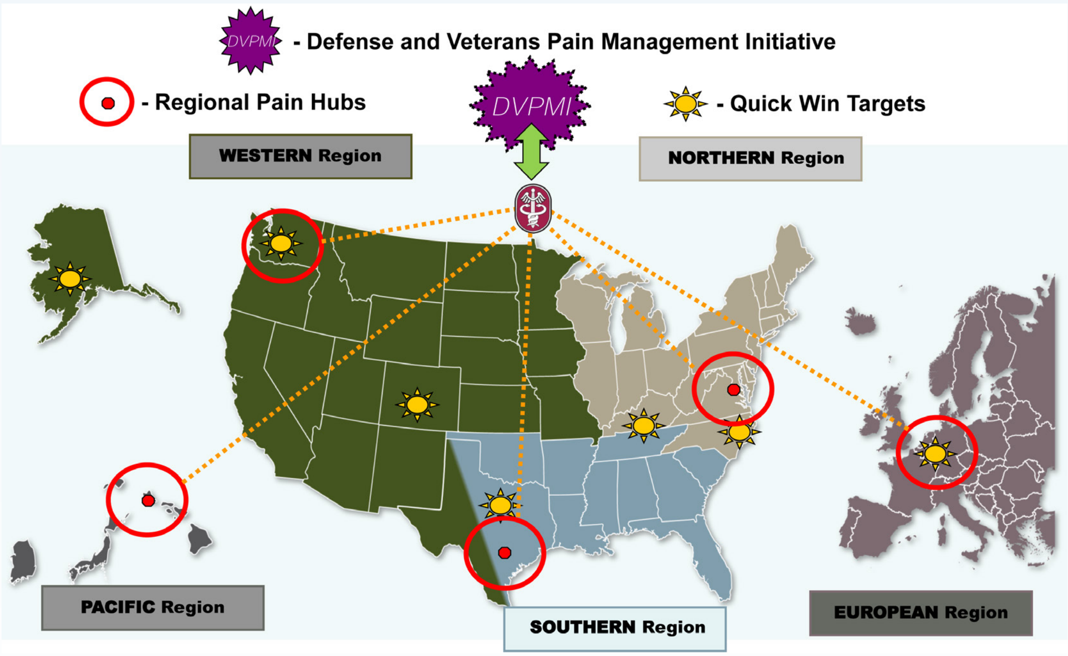
Defense and Veterans Center for Integrative Pain Management **http://www.dvcipm.org/**
Established in 2003 as a CSI initiative and transitioned to DHP core funding in FY10, the DVCIPM focuses on acute and chronic pain research. It provides infrastructure for consultation, referral, policy development, publications, education, and training. The DVCIPM coordinates regional pain management centers (**Figure 1-6**). The DVCIPM works to develop consensus recommendations from the Air Force, Army, Navy, and Veterans Health Administration pain medicine services for improvements in medical practice and technology that will promote interdisciplinary pain management practices in the care of military beneficiaries. The DVCIPM conducts translational research and outcomes evaluation to guide evidence-based practice. Other research topics include novel and traditional analgesics, therapeutic strategies, and biomarkers of pain.
Advisory Role • Functions as a tri-Service and Veterans Health Administration-focused advisory organization for clinical pain medicine, education, and research • Identified by the Office of the Surgeon General (OTSG) Pain Management Task Force as the recommended DoD pain advisory organization • Serves the uniformed Services as an advisory organization on pain medicine throughout the care continuum from the battlefield, during evacuation, and at home
Accomplishments • Developed the Military Advanced Regional Anesthesia and Analgesia Handbook: The First Battlefield Pain Management Text • Developed and deployed acute pain treatment sets for Combat Support Hospitals (or Role 3 care) in Operation Enduring Freedom/Operation Iraqi Freedom • First-ever deployed Acute Pain Service with British Coalition Forces, Camp Bastion, Afghanistan • Defense and Veterans Pain Management Initiative – SME to US Army OTSG on Pain Task Force • Spearheaded first battlefield research since WWII on pain immediately following wounding (accepted for publication) • OTSG accepted DVCIPM recommendation to appoint Specialty Consultant for Pain • Commendation from the American Pain Society for Innovation in Pain Management • Development of the Defense and Veterans Pain Rating Scale that is presently being established as the standard for pain screening within the DoD
Research Highlights • Evaluation of early aggressive intervention using advanced regional anesthetic techniques on chronic neuropathic pain and comorbidities • Identification of differential protein expression following traumatic sciatic nerve injury • Effect of continuous peripheral nerve blocks for treatment of post-amputation phantom limb and stump pain • Current active research protocols in integrative medicine for pain management in areas of acupuncture, massage therapy, and yoga • Use of unbiased plasma proteomics to identify biomarkers of neuropathic pain • Program evaluation of the implementation of Patient Assessment and Outcomes Registry (PASTOR) and Patient-Reported Outcomes Measurement Information System (PROMIS), an electronic clinical pain assessment and tracking tool in collaboration with the National Institutes of Health (NIH).

Integrative Pain Management (DVCIPM), and the Vision Center of Excellence. Details on the DVCIPM are depicted in **Table 1-3**.

While those mentioned are not a full listing of organizations, the PCO works with many programs, research institutes, and centers to facilitate the coordination of blast injury research.

Upcoming Chapters

The following chapters highlight the DoD's research efforts to understand blast injuries and improve its capability to counter the effects of blast. The role of the Blast Injury Research PCO is explained, as is the JTAPIC program, which seeks to learn from blast events. Updates are provided on efforts to monitor warfighter blast exposures and develop computational and predictive models of injury. The State-of-the-Science Meeting Series and the collaboration with the NATO Human Factors and Medicine (HFM) Panels are presented as examples of enhancing collaboration, identifying knowledge gaps, setting research agendas, and disseminating knowledge to solve difficult blast injury problems. Finally, a number of recent research accomplishments are highlighted to show the progress that the DoD is making toward preventing, mitigating, and treating blast injury. The initiatives and accomplishments presented are not all-inclusive but are meant to be representative of the multitude and variety of efforts ongoing in the DoD to protect, treat, and restore our Service members who are exposed to blast events during their service to the nation.



With coordination by the DVCIPM, the IPMCs serve as pain medicine hubs for each Regional Medical Command and are responsible for all local acute, chronic, and cancer pain services within the hosting Military Treatment Facility (MTF). IPMCs serve as the primary pain medicine consultant service for MTFs within a Region. Each IPMC operates within an integrated pain management model that utilizes state of the art/science modalities and technologies to provide optimal quality of life for Soldiers and other patients with acute and chronic pain.

Figure 1-6. Interdisciplinary Pain Management Center (IPMC) Framework

Chapter 2

DoD Blast Injury Research Program Coordinating Office

Vision: To establish and maintain a fully coordinated DoD blast injury research program as envisioned by Congress and directed by the Secretary of Defense.

Mission: The Blast Injury Research PCO assists in fulfilling the DoD Executive Agency responsibilities and functions related to medical research for the prevention, mitigation, and treatment of blast injuries in accordance with DoDD 6025.21E by coordinating and managing relevant DoD medical research efforts and programs, identifying blast injury knowledge gaps, shaping medical research programs to fill identified gaps, facilitating collaboration among diverse communities within and outside of the DoD, and widely disseminating blast injury research information.

The DoD medical research community has a long history of conducting medical research on blast-related injuries and has produced tremendous advances in battlefield medicine that are responsible for preventing blast injuries and saving the lives of blast-injured Service members. This research has also produced biomedically valid blast injury prediction models and performance standards that serve as the basis for combat platform occupant and personal protection system designs, as occupational exposure standards for blast-producing weapon systems, and as survivability assessment tools and metrics for combat platform occupant survivability assessments.

Researchers in other federal agencies, academia, and industry have also made significant contributions to the study of blast injury prevention, mitigation, and treatment. The PCO is taking full advantage of the body of knowledge and expertise that reside both within and outside of the DoD to solve complex blast injury problems.

Key PCO Functions

Key functions of the Blast Injury Research PCO include:

Identify Blast Injury Knowledge Gaps

The study of blast injury involves many fields of research, multidisciplinary approaches, and a difficult problem set. It is critical for program managers and researchers to understand where to focus their attention and to make sense of the information coming out of the research projects. Some of the means the PCO uses to identify knowledge gaps include:

- **State-of-the-Science Meetings.** The PCO instituted a State-of-the-Science Meeting Series to assist in identifying knowledge gaps pertaining to key blast injury issues. These focused meetings help determine what is known and what is not known about a particular blast injury topic. See Chapter 6 for more information on the meeting series.
- **DoD Brain Injury Computational Modeling Expert Panel.** An expert panel has been established to assess the state of research in computational modeling of non-impact blast induced brain injury to identify critical knowledge gaps, develop a research roadmap to address the gaps, and monitor progress in resolving the knowledge gaps. See Chapter 4 to learn more about this effort.

- **NATO HFM Panels.** The PCO participates and leads NATO technical panels that bring together the international community interested in blast injury research. These panels serve as a sharing mechanism to understand what knowledge gaps exist worldwide and how they are being addressed. See Chapter 5 to learn more about this effort.

Disseminate Blast Injury Research Information

The PCO serves as a resource to members of the DoD, other federal agencies, academia, and industry regarding blast injury research and programs. Some of the mechanisms used to provide this resource include:

- **Website.** The PCO has established a website (https://blastinjuryresearch.amedd.army.mil) to provide current information on the DoD Blast Injury Research Program and allow individuals and organizations to submit blast injury-related questions directly to the PCO.
- **Responding to Inquiries.** The PCO provides coordinated responses to scientific and programmatic inquiries regarding blast injury research and effects from all levels, including Congress, DoD and Service component leadership, other DoD organizations, industry, and academia. Products provided to DoD leadership include programmatic information, review of policy and guidance recommendations, and status reports on active projects. Often, it is merely a matter of linking the inquirer with the right PCO partner or organization to respond.
- **Meetings.** The PCO actively seeks out stakeholders, within DoD and with partner nations, to inform them of the DoD's efforts in blast injury research as well as to learn about their programs, problem sets, and initiatives. Some of these efforts are described in the Recent PCO Activities section in this chapter.

- **Linking Researchers.** The PCO is able to use its network of research programs and knowledge of active blast injury research to link researchers from government, academia, and industry with common areas of interest.

Shape Research Programs to Fill Knowledge Gaps

It is critically important to incorporate information on knowledge gaps into the biomedical research program planning processes. To ensure blast injury knowledge gaps are addressed in DoD medical research programs, the PCO staff participate as voting members and/or interact with numerous research program planning and management committees, including:

- **Joint Program Committees.** The JPCs, with membership from the component Services, VA, NIH, the science and technology community, and the operational and requirements community, are responsible for developing research program plans and program announcements, reviewing research proposals for programmatic relevance, and evaluating research progress.
- **Joint Technology Coordinating Groups.** These groups are organized under the ASBREM Committee and are responsible for coordinating medical research programs across the Services, including programs that address blast injury research topics in the areas of MOM, CCC, and CRM.
- **Integrating Integrated Product Teams (IIPTs).** The IIPTs were created to implement a team approach to manage biomedical science and technology at USAMRMC. IIPT membership consists of personnel from the combat development community and SMEs from DoD, academia, and other organizations. The IIPTs are responsible for advising the USAMRMC Research Area Directors on the current focus and future direction for ongoing research efforts.
- **Research Advisory Committees (RACs).** PCO participation on RACs helps to inform the researchers and sponsoring programs of new developments and related efforts. For example, the PCO director participated on the External Advisory Board for the congressionally funded "Trauma Mechanics Research Initiative" at the University of Nebraska at Lincoln, which is focused on computational modeling of blast-related TBI and other injuries.

Promote Information Sharing and Partnerships

Both the blast threat and the mitigation solutions are multidisciplinary problems that require the continued interaction of many diverse organizations across DoD to be succesful. In the past, many of these organizations may have only approached the problems from their own individual perspective. The PCO is actively engaged in linking organizations and establishing and maintaining partnerships to ensure this success. The following are descriptions of two critical partnerships.

- **Overseeing the Joint Trauma Analysis and Prevention of Injury in Combat Program.** The JTAPIC Program is executed as a virtual matrix organization consisting of partner organizations from the DoD medical, materiel, operational, and intelligence communities whose efforts are integrated by the JTAPIC Program Management Office (PMO). The JTAPIC Program facilitates the joint collection, integration, and analysis of data and information to improve our understanding of vulnerabilities to threats and enable the development of improved tactics, techniques, and procedures (TTPs), requirements, material solutions, models, etc., to prevent and mitigate injuries. See Chapter 3 for more information on the JTAPIC Program.

- **Coordinating the Medical R&D Effort of the Under Body Blast (UBB) Warrior Injury Assessment Manikin (WIAMan) Program.** Under the direction of the Deputy Assistant Secretary of the Army for Research and Technology, the WIAMan program is developing improved capabilities for the Live-Fire Test and Evaluation (LFT&E) community. The goal of this effort is improved manikins, methodologies, metrics, and injury criteria to assess the potential for injury based on accelerative loads sustained during UBB testing of vehicle platforms and protective technologies. This effort involves performers from across the DoD, including medical and non-medical R&D and the test and evaluation community. The WIAMan program offers the potential for enhanced vehicle and warrior survivability.

Facilitate Collaboration Both Within and Outside DoD

Information and research capabilities related to blast injury research can be found both within and outside of the DoD. By collaborating, the programs can advance further and faster toward solutions. Examples are provided to show how collaboration is benefiting DoD and ultimately warfighter survivability.

- **Recommending Blast Injury Prevention Standards, Including Protective Equipment Performance Standards for the DoD.** The PCO, in collaboration with the PCO, in collaboration with the Johns Hopkins University (JHU) Applied Physics Laboratory (APL), a University Affiliated Research Center and DoD trusted agent, has developed an unbiased, inclusive, stakeholder-driven process for identifying and recommending Military Health System (MHS) Blast Injury Prevention Standards. This process, known as the MHS Blast Injury Prevention Standards Recommendation (BIPSR) process, fulfills a key responsibility of the EA and ensures that the DoD is using the best available, biomedically valid standards to develop safe weapon systems, survivable combat platforms, and effective protection against blast-related threats. See Chapter 4 for more on the BIPSR process.

- **Sharing USAMRMC Injury Models with the Navy.** The objective of the Navy's Human Injury Treatment (HIT) modeling and simulation (M&S) project is to provide the Navy LFT&E community with a computer modeling tool for ship survivability assessments. The PCO has established a Memorandum of Understanding between the Office of Naval Research (ONR) and the USAMRMC that enables the transfer of USAMRMC injury prediction models to ONR for insertion into the HIT toolset. In return, ONR will provide formal verification and validation of the USAMRMC models.
- **Leveraging Expertise from Industry, Academia, and Federal Agencies to Solve Difficult Blast Injury Problems.** The PCO continues to establish and expand relationships to coordinate efforts, conduct collaborative activities, obtain needed expertise, and solve problems. Through interactions with other organizations, working groups, and meetings, the PCO has developed an extensive network that it can call on to support the program's efforts. Examples include the DoD Brain Injury Computational Modeling Expert Panel, the State-of-the-Science Meeting Series, and the BIPSR process.

Recent PCO Activities

Since its inception, the PCO has made significant progress in effectively coordinating DoD blast injury research. Examples of FY12 activities by the PCO include:

Identification of Blast Injury Research Knowledge Gaps

- **Neurosensory Polytrauma.** The PCO facilitated a meeting with the Hearing and Vision CoEs, the National Intrepid Center of Excellence (NICoE), Center for the Intrepid, the Chairs of the JPCs for CCC, MOM, and CRM, and the Telemedicine and Advanced Technology Research Center (TATRC) to discuss the need for a coordinated medical research approach to addressing neurosensory polytrauma. The CoEs agreed to develop an integrated gap assessment document to assist the JPCs in evaluating current/planned research programs and where to focus for additional research.
- **Limb Salvage and Rehabilitation.** The PCO began planning for the fourth State-of-the-Science meeting, which is anticipated to occur in 2nd Quarter (2Q) FY14. The meeting will address topics in limb salvage and rehabilitation and develop recommendations for future research. See Chapter 6 for more information on the State-of-the-Science Meeting Series.

International Cooperation and Collaborative Activities

Not all knowledge of blast injury prevention, mitigation, and treatment resides within the United States. Therefore, the PCO hosts international experts and participates in international meetings to facilitate an exchange of information and ideas, pursue opportunities to leverage the research and experience from other countries, and explore opportunities for developing common international standards for future joint operations. Some of the efforts are described in the following bullets.

- **International Terrorism.** The PCO participated in the annual Threat Day that served as the kickoff for the Combating Terrorism Technology Support Office (CTTSO) FY13 Business Planning Cycle. The agenda focused on international efforts to combat terrorism and included classified briefings from representatives of Australia, Canada, Israel, Singapore, and the United Kingdom (UK). The information presented at this event will be used during the CTTSO/TSWG requirements-setting meetings.
- **Australia.** The JTAPIC Program and Program Executive Office (PEO) Soldier presented an overview of the Generation (Gen) II Helmet Sensor project to Brigadier General (BG) Rerden and the Australian delegation at the Association of the United States Army annual meeting hosted by Deputy Assistant Secretary of the Army for Defense Exports and Cooperation. The Australians were interested in exploring opportunities to partner with the United States on the Helmet Sensor project.
- **United Kingdom.** The JTAPIC Program Manager briefed Major General (MG) Jeremy Rowan, Assistant Chief of Defense (Health), UK, on the JTAPIC Program. MG Rowan was keenly aware of the JTAPIC Program and the parallel efforts being conducted in the UK. MG Rowan shared the concern over the loss of such capabilities as hostilities are reduced and Soldiers are redeployed, and he expressed great interest in the Wounded Warrior Interview Program.
- **Germany.** The JTAPIC Program Manager attended the NATO Incident Exploitation Working Group (IEWG) Meeting in Meppen, Germany. The IEWG nations provided unclassified presentations of their capabilities, methods, and tools used to conduct incident investigation, analysis, and reporting. Germany, the UK, and the United States presented their unclassified trauma analysis capabilities, methods, and tools.
- **Canada/NATO.** The PCO Director co-chaired the NATO Research and Technology Organization, HFM Panel Symposium (HFM-207) on "A Survey of Blast Injury Across the Full Landscape of Military Science," in Halifax, Canada. More than 130 scientists, clinicians, and engineers, representing nine NATO countries, participated in this symposium. The presentations addressed the scope of the blast injury problem, the complexity of blast injuries, blast injury mechanisms, and materiel and therapeutic approaches to mitigating blast injuries. The symposium recognized the importance of a systematic approach to understanding blast injuries and the pressing need for a multidisciplinary approach to address nonpenetrating blast injuries to the brain that result in a host of symptoms with vague etiology; a recommendation was made to form a new NATO HFM Panel Research and Technology Organization Task Group (RTG).
- **NATO.** The PCO Director was nominated to chair a new NATO RTG called, "HFM-234, Environmental Toxicology of Blast Exposures: Injury Metrics, Modeling, Methods and Standards." This RTG is an offshoot of the research symposium (HFM-207) mentioned earlier. The RTG has been formally approved and formal nominations from RTG member nations are pending. See Chapter 5 for more on the RTG and the research symposium.

Support to DoD Leadership

Part of the PCO responsibility is to support DoD leadership with information and assessments to respond to blast injury issues. A few examples of such support are:

- **Behind Body Armor Effects.** The PCO provided an information paper to senior Army leadership on the "Effects of Body Armor and the Advanced Combat Helmet (ACH) on Primary Blast Injuries" to refute the assertion in Army and civilian medical literature and the Textbook of Military Medicine that the wearing of body armor accentuates (worsens) the effect of blast on internal organs.
- **Protection from TBI.** The PCO provided an information paper to the Secretary of the Army in preparation of his testimony to the House Armed Services Committee on the types of materiel solutions being used to help protect against TBI.
- **Blast Exposure Sensors.** The PCO updated SecArmy of the Army on USAMRMC's role in PEO Soldier's Gen II helmet-mounted sensor system (HMSS) fielding initiative to support testimony at the House Armed Services Committee Posture Hearing. The update emphasized PEO Soldier's lead role and identified the JTAPIC Program's efforts in leading a sensor data analysis project to determine whether sensor data correlate with events and injuries, and to develop an operational exposure screening tool to indicate the probability of concussion.
- **Organization Transformation.** An overview of the PCO and JTAPIC Program to Ernst and Young, LLC, to inform them in their role helping the Surgeon General transform the Army Medical Department into an operating company model.
- **R&D Funding and Application.** The PCO responded to a Request for Information (RFI) from Congresswoman Ileana Ros-Lehtinen on the USAMRMC's level and distribution of funding for TBI R&D and on its stand on implementing TBI research into better helmets.

PCO in the News

- **Multiple Amputations from IEDs on the Rise.** The PCO and JTAPIC leadership participated in a telephone interview with USA Today regarding the number of multiple amputations that occurred during Operation Enduring Freedom (OEF). The JTAPIC leadership verified data provided to USA Today by the US Army Institute of Surgical Research's (USAISR) Joint Trauma System that there was an aggregate decline in number of Service members experiencing amputations with an incline in the number of multiple amputations. The USA Today article, "IEDs contribute to increase in multiple amputations," was published on Jun 4, 2012 (http://www.usatoday.com/news/military/story/2012-06-04/IED-amputations-military-Afghanistan/55385376/1).
- **Blast Sensor Fielding and Data Analysis.** The Daily Tech website published an article addressing the Soldier Body Unit sensor pack, a component of the larger Integrated Blast Effect Sensor Suite (I-BESS). The article noted, "The data collected by the sensors will be sent to the JTAPIC, where the information will be examined by medical professionals. They hope that these sensors will help indicate when Soldiers have head injuries so that they can be properly treated and protected." The Daily Tech article "US Military Receiving Updated Blast Sensors for Head Injuries"

was published on June 1, 2012 (http://www.dailytech.com/US+Military+Receiving+Updated+Blast+Sensors+for+Head+Injuries/article25286.htm).

Informing Protective Equipment Development

The medical research community has always played a critically important role in the development of individual and combat platform occupant blast protection equipment and systems by providing materiel developers with biomedically valid injury criteria, performance standards, and testing methods. The PCO continues to strengthen and expand this important relationship as illustrated in the following activities:

- **Risk Assessment.** The PCO, in coordination with the MOM Research Program (MOMRP), obtained approval to release MOMRP's blast lung injury prediction software application known as "INJURY" to the Technical Team for NATO HFM-198, "Injury Assessment Methods for Vehicle Active and Passive Protection Systems." This team requested the INJURY application to assess potential blast lung injury risks in a series of planned live-fire tests.
- **Blast Exposure Sensors.** The PCO serves as the medical lead for the Vice Chief of staff of the army's (VCSA) HMSS fielding initiative. The JTAPIC Program is conducting sensor data analysis in support of this and other battlefield sensor fielding initiatives. See Chapter 4 for more on the sensor data analysis effort.

- **WIAMan Program.** The PCO served as the lead for the medical research component of the WIAMan program, which is developing a warrior representative anthropometric test device (ATD) and associated biomedically validated injury criteria that can be used to characterize dynamic events and injury risks for live-fire assessment and vehicle development efforts to better protect warriors from UBB threats. In October 2012, management of the WIAMan Program and associated funding was transferred to the Research, Development and Engineering Command (RDECOM). This change provides for centralized coordination of all program activities.
- **Research Program Planning.** The PCO participates on program planning and review panels to identify blast-related knowledge gaps and help set research program strategies.
- **PEO Soldier.** The PCO and JTAPIC briefed BG Camille M. Nichols, PEO Soldier. A key discussion point included the JTAPIC process by which data are coalesced into actionable information and information products, and the resulting decisions they fostered. BG Nichols suggested several initiatives to mine existing data and was insistent that the information potentially generated from this process cannot wait for an RFI to call it out.
- **Behind Armor Blunt Trauma.** The PCO and JTAPIC facilitated a meeting with representatives from the Office of the Director, Operational Test and Evaluation (DOT&E) and the USAMRMC MOMRP to discuss the recently published National Research Council (NRC) report "Testing of Body Armor Materials: Phase III." The NRC made recommendations for improved body armor and helmet testing methods that focus on an understanding of the injuries these systems are designed to prevent, and it suggested taking advantage of real-life injury data to

support the development of improved testing methods. The group also discussed MOMRP's biomedical research projects on injury metrics and testing methods for body armor and combat helmets, as well as opportunities for JTAPIC to support the research with relevant injury data.

Advancing Science and Medicine

The PCO's role in informing research/program managers and fostering collaborations contributes to advancing science and medicine. Examples of how the PCO impacts this advancement are:

- **US Army Research Laboratory (ARL) Science and Technology Panels.** The PCO participated in the ARL, Weapons and Materials Research Directorate (WMRD) Science and Technology Program Review. The WMRD plays a key role on the PCO-sponsored, DoD Brain Injury Computational Modeling Expert Panel that is attempting to develop a research roadmap for the development of a biomedically valid computational model of non-impact, blast-induced mTBI.
- **Concussion/mTBI Management.** JTAPIC provided input to the DCoE related to the impact of the implementation of Directive-Type Memorandum (DTM) 09-033, "Policy Guidance for the Management of Concussion/ Mild Traumatic Brain Injury in the Deployed Setting." This DTM was reissued as a DoD Instruction (DoDI) 6490.11, "DoD Policy Guidance for the Management of Mild Traumatic Brain Injury/Concussion in the Deployed Setting" on September 18, 2012.
- **University of Nebraska-Lincoln (UNL).** The PCO participated on the External Advisory Board for the congressionally funded "Trauma Mechanics Research Initiative" at the UNL. The research initially focused on computational modeling of blast-related TBI but has expanded to include studies of other types of blast-related injuries, including those caused by UBB. The team published a study on blast wave interactions with the bare and helmeted head that demonstrated that the ACH with properly configured pads provides blast protection by attenuating blast pressures under the helmet. This finding contradicts previously reported findings that the combat helmet focuses and enhances the blast wave.

- **Institute for Collaborative Biotechnologies and Institute for Soldier Nanotechnologies.** The PCO hosted a meeting between two University Affiliated Research Centers, the Institute for Collaborative Biotechnologies and the Institute for Soldier Nanotechnologies, and representatives from various Army research groups that focused on upcoming research plans investigating the cognitive aspects of mTBI.
- **Biomechanically Based Auditory Standard.** The PCO participated as an advisor at a project review meeting for the "Biomechanically Based Auditory Standard" research project managed by TATRC. The goal of this project is to develop a biomechanical-model-based impulse noise auditory injury standard as a candidate to replace the impulse noise limits in the current Military Standard (MIL-STD) 1474D used by the weapon system development, test and evaluation, and medical communities, to design, build, test, and evaluate weapon systems that produce impulse noise. The current MIL-STD is considered overly conservative and restrictive. As a candidate

MHS Blast Injury Prevention Standard, the product of this research may undergo an independent review in the newly established MHS BIPSR process.

Linking with Other Federal Agencies and Industry

- **First Responder Injury Mitigation.** The JTAPIC Program Manager met with the Director, Medical Preparedness Policy, National Security Staff (NSS), and the Office of Science and Technology Policy, the White House, to identify how JTAPIC could assist the NSS in writing policy regarding personal protection equipment and injury mitigation for first responders. The JTAPIC Program will collaborate regarding injury patterns. Subsequently, JTAPIC participated in a NSS-sponsored Working Group Meeting to discuss first responder preparedness and response to an IED event with the overall intent to establish national policy and programs. The JTAPIC shared IED threat information, injury types and severity, and injury mitigation strategies to prevent or mitigate injuries as a means to inform their planning and programming process.

Chapter 3

Joint Trauma Analysis and Prevention of Injury in Combat Program

The JTAPIC partners provide jointly identified solutions that enhance warfighter survivability.

The JTAPIC Program was established at USAMRMC, Fort Detrick, in July 2006 to assist in fulfilling portions of the Secretary of the Army's EA responsibilities under DoDD 6025.21E ("Medical Research for Prevention, Mitigation and Treatment of Blast Injuries"). The JTAPIC Program's mission is to collect, integrate, analyze, and store operations, intelligence, materiel, and medical data to inform solutions that will prevent or mitigate injury during the full range of military operations.

Prior to establishment of the JTAPIC Program, military organizations focused on improving warfighter survivability individually rather than collaboratively. The medical community focused on battlefield medicine and increasing warfighter survivability by using the best medical and treatment modalities available. Protective equipment developers focused on performance specifications and the development of process improvements under testing conditions because few articles were returned from killed in action (KIA) or wounded in action (WIA) events for analysis. When an article was returned, the analysis was performed without the benefit of full knowledge of the operational context or the injuries sustained by the warfighter. Operational context means understanding what happened to the warfighter and what he or she was doing at the time of injury. When vehicle improvements were fielded in Operation Iraqi Freedom (OIF), there was no formal process to provide vehicle developers with relevant contextualized medical information on combat injuries that could allow them to understand how well vehicles protected their occupants. Conversely, for the medical community, no formal process existed for providing medical injury data associated with combat operations to nonmedical users, such as combatant commanders (COCOM), materiel developers, and requirement developers.

To streamline and enhance joint Service information sharing and collaboration for the analysis and prevention of injuries in combat, the JTAPIC Program established a joint "matrixed" partnership (**Table 3-1**). SMEs stay embedded in their core organizations while their efforts are integrated and coordinated by the JTAPIC PMO. As shown in **Figure 3-1**, the program links the DoD medical, intelligence, operational, and materiel development communities with a common goal of collecting, integrating, and analyzing injury, materiel performance, and operational data to improve the understanding of vulnerabilities to threats. It also enables the development of improved TTPs and materiel solutions that will prevent and/or mitigate traumatic injuries.

The JTAPIC Program by definition is a relationship of multiple agencies coming together to prevent and mitigate traumatic injuries in combat. Since its inception, the program has proven to be an invaluable asset to the Army and the DoD. The collaborative efforts of the JTAPIC PMO and its partners have generated significant cost savings by providing combat event, injury analysis, and actionable information to Service materiel developers, the US Army Training and Doctrine Command (TRADOC), and other senior decision makers.

The JTAPIC Program has received personal endorsements from the VCSA, Secretary of the Army, OSD DOT&E, the Surgeon General of the Army, Project Manager (PM) Stryker, PM Mine Resistant Ambush Protected (MRAP) Vehicles, and the US Army Materiel Command Surgeon. The National Museum of Civil War Medicine awarded the annual Major Jonathan Letterman Award for Medical Excellence to the JTAPIC Program in 2010 to recognize its contributions to the advancement of medical processes and improved patient outcomes and quality of life.

In summary, to adequately analyze a combat event, the JTAPIC Program gathers information from disparate sources with varying levels of classification and links cause (incident operational data and analysis), effect (injury and CCC data and analysis), and mitigation (materiel performance data and forensic equipment analysis) factors. JTAPIC information has allowed for focused vehicle improvements, modular application of survivability systems, and reduction in casualties and vehicle damage (in terms of severity and number of damaged vehicles).

Table 3-1. Members of the JTAPIC Partnership and Their Primary Roles

JTAPIC Partner	Function
Armed Forces Medical Examiner System	Provides information, analysis, and subject matter expertise on KIA.
US Army Maneuver Center of Excellence, Dismounted Incident Analysis Team	Provides operational and intelligence information and analysis of dismounted casualty-causing combat events.
Joint Trauma System	Conducts classified and nonclassified data analysis.
Marine Corps Intelligence Activity	Provides operational and intelligence information.
Naval Health Research Center	Provides information, analysis, and subject matter expertise on WIA.
US Army Aeromedical Research Laboratory	Provides analysis of aircraft and vehicle injury patterns.
US Army Institute of Surgical Research	Provides information, analysis, and subject matter expertise on WIA.
Program Manager, Infantry Combat Equipment	Assesses combat-damaged clothing and equipment.
Marine Corps Systems Command PM, Soldier Protection and Individual Equipment	Provides analysis of combat-damaged PPE.
US Army National Ground Intelligence Center, Combat Incident Analysis Division	Provides operational and intelligence information and analysis of mounted casualty-causing combat events.
US Army Research Laboratory, Survivability/Lethality Analysis Directorate	Provides M&S expertise and analytic support.
US Marine Corps Current Operations Analysis Support Team	Provides operational and intelligence information.

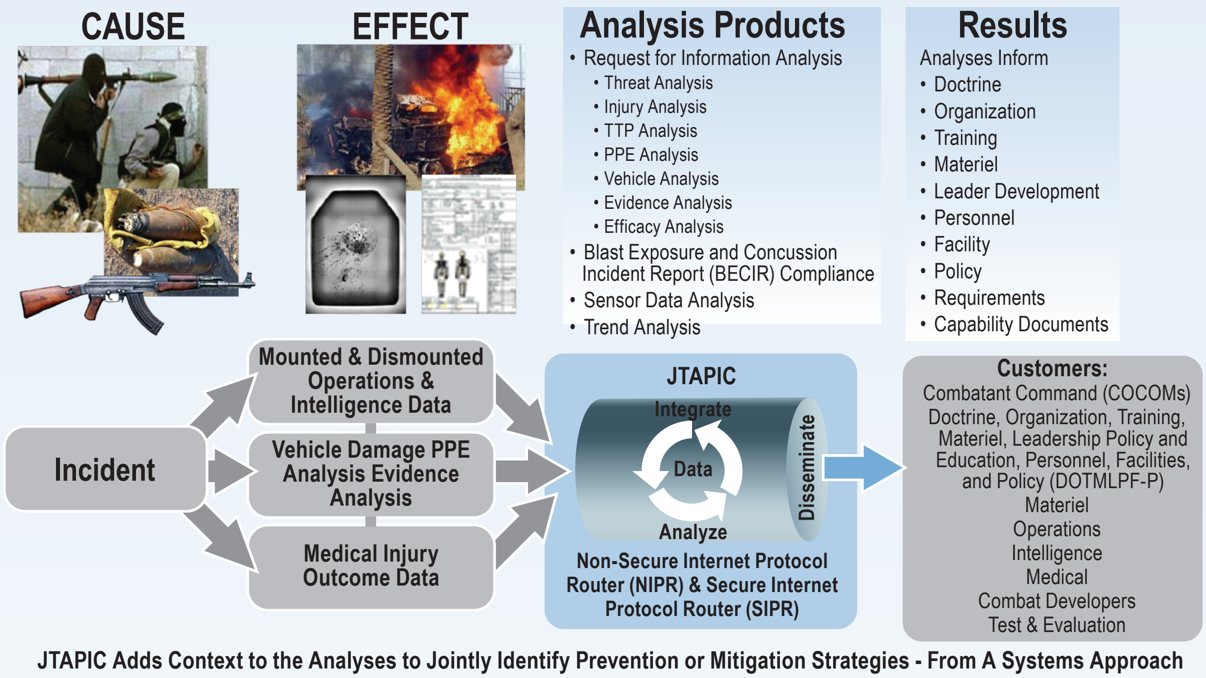


Figure 3-1. JTAPIC Operational Concept

Program Structure

The overall organization of the JTAPIC PMO is shown in **Figure 3-2**, and the JTAPIC project areas and key products are depicted in **Figure 3-3**. In FY12, a Program Manager role was added for oversight of the mTBI and blast sensor project areas.

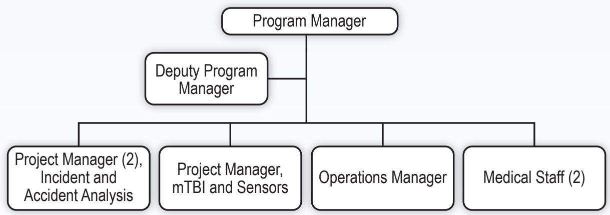


Figure 3-2. JTAPIC PMO Structure

Mounted Analysis Project Area

The mounted analysis project area analyzes events involving injury to mounted warfighters (those in combat vehicles) to determine prevention and mitigation strategies. This project area is further broken down into two product areas: mounted combat incident analysis and accident/mishap analysis. When the nation is at war or in combat, the mounted combat incident analysis product area focuses on analysis of the contextualized injury patterns and trend of attacks against combat vehicles. Analyses from this product area are pushed to the vehicle PMs and other Service materiel developers to determine mitigation strategies in the form of modifications and upgrades. The accident/mishap analysis product area has both a wartime and peacetime mission for linking operational, medical, and equipment data. Injuries resulting from accidents are analyzed to determine what preventive measure(s) can be implemented to prevent or mitigate these injuries in future accidents.

Dismounted Analysis Project Area

The dismounted analysis project area analyzes events involving injury to dismounted warfighters to determine prevention and mitigation strategies. The dismounted analysis project area has two product areas: combat analysis and training analysis. During wartime, the combat analysis product area analyzes incidents involving dismounted warfighters, looking at the injury types and trends caused by particular weapons. These analyses are provided to Service materiel developers and TRADOC to influence protective equipment design and TTPs, respectively. During peacetime, the dismounted training analysis

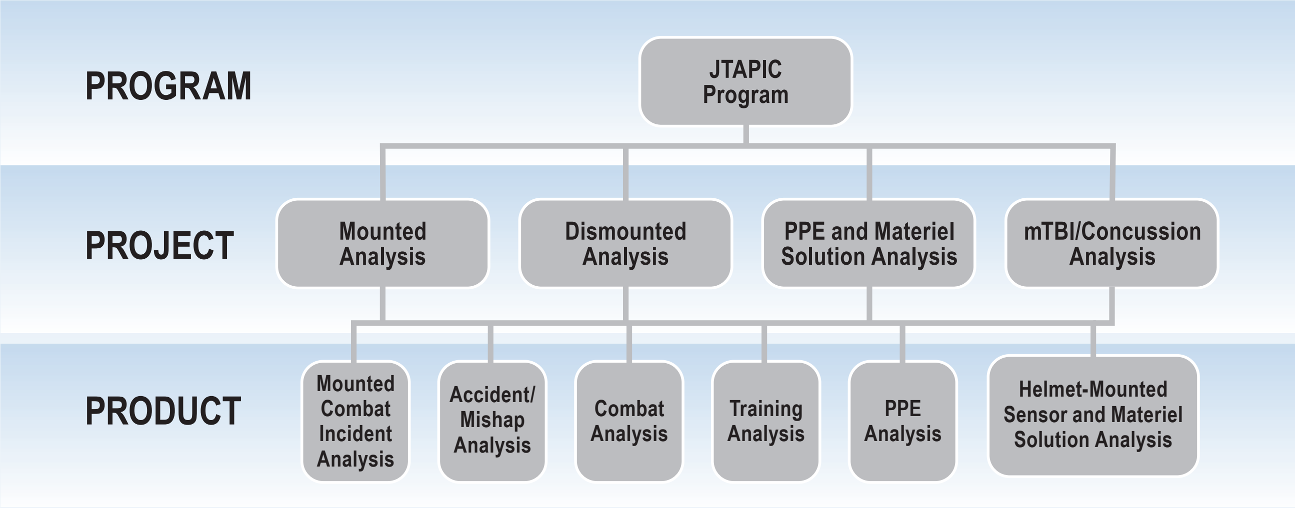


Figure 3-3. JTAPIC Program Structure

product area will look at training incidents and the injuries they cause. The objective is to understand the types and prevalence of injuries occurring during training and push these analyses to the materiel developers and TRADOC. JTAPIC will continue to perform event reconstructions on selected mounted and dismounted combat events via M&S; it will also perform comparative analysis between combat events and live-fire tests. Combat event analysis case studies will be used for instructor professional development at Army leadership courses such as the Infantry Basic Officer Leadership Course.

mTBI and Concussion Project Area

The mTBI and Concussion Project Area was added to the JTAPIC Program in FY12. This area supports the implementation of policy and guidance for the management of mTBI/concussion and also the analysis of data from blast exposure sensors. In support of DoDI 6490.11, Policy Guidance for Management of mTBI/Concussion in the Deployed Setting, the JTAPIC Program supports the Identify-Evaluate-Treat-Manage continuum, collects the Blast Exposure and Concussion Incident Report (BECIR) from COCOM, and measures COCOM compliance with the DoDI. In addition, the JTAPIC Program correlates sensor data with injury data in the electronic health record (EHR) and collaborates with the DCoE on mTBI analysis. Currently, the JTAPIC Program is providing data analysis in support of three blast sensor initiatives: the I-BESS, PEO Soldier's HMSS, and the DARPA Blast Gauge. The JTAPIC Program is also the DoD repository for all sensor data from the Services. These sensors provide an objective means for commanders to identify Service members who have been exposed to a potentially concussive event as well as support research efforts to develop dose-response models for blast injury. For more on the sensor efforts, see Chapter 4.

PPE and Materiel Solution Analysis

The JTAPIC Program collects PPE that has been damaged in some way from KIA and WIA events and conducts analysis to understand its capabilities, vulnerabilities, and serviceability. Based on performance and injury trends, technology inserts are developed. The JTAPIC Program collects fragments and conducts metallurgical analysis and reverse engineering to determine velocities of fragments. Metallurgical analysis helps in understanding the distribution of sizes and weights of the fragments and in identifying threats.

The Benefits of Partnership

The primary benefit of the JTAPIC partnership is the ability to leverage cross-functional SMEs from multiple organizations across military Services to collect, integrate, analyze, and store operational, intelligence, materiel, and medical data to inform solutions that will prevent or mitigate injury during the full range of military operations. The combined JTAPIC Program has made a difference in the way we protect warfighters from blast-related injuries. The analysis of recovered materiel has confirmed the presence of prominent threat weapons of interest to the intelligence community. The project teams have used incident, injury, and autopsy data to identify potential vulnerabilities in operational procedures, and they have rapidly conveyed these vulnerabilities to commanders in theater. The Mounted Analysis Project Area provided actionable information to combat vehicle PMs that led to the modification of vehicle equipment to prevent or mitigate blast-related injuries. The JTAPIC Program supports the DCoE in its role in monitoring mTBI/concussion events. The PCO also recently engaged with the White House NSS regarding injury mitigation for first responders. Examples of recent JTAPIC partnering efforts are shown in **Table 3-2**. Another key benefit of the JTAPIC Program is its ability to provide coordinated responses to inquiries from across the DoD.

The JTAPIC Program holds frequent partnership meetings to encourage collaboration and as a means to conduct analyses. FY12 meeting topics included reviews of mounted and dismounted combat events and forensic event analysis to identify recommendations for injury prevention or mitigation. Other meetings in FY12 included a Lean Six Sigma Tiger Team meeting involving a review of the JTAPIC RFI process, a meeting involving the examination of 10 specific combat events of interest using the Doctrine, Organizations, Training, Leader Development, Materiel, Personnel and Facilities and Policy review process to identify potential issues and recommendations, and a meeting with staff at the Joint Pathology Center's Biophysical Toxicology and Depleted Uranium/Embedded Metal Fragment Laboratories Branch.

Key Initiatives

The JTAPIC Program developed numerous initiatives to ensure its information-sharing capability remains responsive to the needs of the entire DoD community.

International Outreach

As a part of the Technical Cooperation Program Action Group 3 (Mitigation of Battlefield Trauma), the JTAPIC Program assists in conducting activities to improve the understanding of the mechanisms of battlefield trauma and establishes links between protection system

Table 3-2. Examples of JTAPIC Partnering Efforts

Partnering Organization	Description of Partnering Effort
Joint Improvised Explosive Device Defeat Organization (JIEDDO)	JTAPIC participated in a meeting at JIEDDO on February 29, 2012 in which JIEDDO expressed its need for blast-related medical data to identify injury trends based on area of operation and incident-specific information. JTAPIC explored opportunities to work with JIEDDO to meet its needs while preventing unnecessary duplication of the JTAPIC mission. JTAPIC began participating in the JIEDDO weekly secure Video Teleconferences and invited JIEDDO to participate in JTAPIC Partners meetings.
US Forces Afghanistan (USFOR-A), US Central Command (CENTCOM) Surgeons, and Office of the Surgeon General	JTAPIC received a request from theater (Task Force Medical-Afghanistan) in March 2012 requesting guidance on entering information from the DARPA Blast Gauge (**Figure 3-4**) into medical records. JTAPIC worked with the USFOR-A and CENTCOM Surgeons, and the OTSG to develop and implement a USFOR-A theater policy directing documentation in the EHR for Service members who are referred for medical evaluation in response to a sensor (helmet or DARPA Blast Gauge) indication of exposure to a blast event. Concurrent work focused on implementing how and where to document the environmental exposure in the EHR for the purpose of correlating exposure and injury data.
US White House	On September 12, 2012, JTAPIC participated in a White House NSS-sponsored working group meeting to discuss first responder preparedness and response to an IED event with the overall intent to establish national policy and programs. The JTAPIC Program shared IED threat information, injury types and severity, and injury mitigation strategies to prevent or mitigate injuries as a means to inform its planning and programming process.

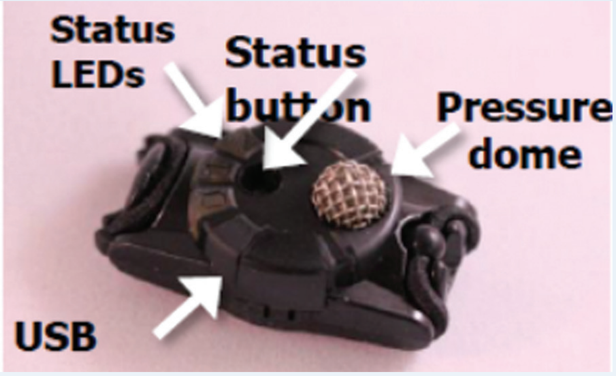


Figure 3-4. The DARPA Blast Gauge

performance and injury patterns in the context of current and future operations. The Action Group 3 encompasses representatives from Australia, Canada, UK, and the United States. Each participating nation has established (or is establishing) its own respective JTAPIC-like program. JTAPIC was recognized in February 2013 by the Assistant Secretary of Defense for Research and Technology for its contributions to the Technical Cooperation Program. JTAPIC contributed to creating a community of interest within the Land Systems Group, Action Group 3, aimed at mitigating battlefield trauma through a Soldier-centric approach to survivability. JTAPIC's contributions expedited national procurement activities that significantly contributed to saving warfighters' lives or reducing the severity of their injuries.

Additionally, the JTAPIC Program continues to participate as part of the Five Power Senior National Representatives Army (5P SNR[A]). The 5P SNR(A) consists of representatives from France, Germany, Italy, UK, and the United States. The 5P SNR(A) was formed to look at solutions that are potentially useful to NATO. The 5P SNR(A) has had success in discussing ideas in small working groups and then providing concepts to be approved by the 5P Heads of Delegation. Once completed, they then present to NATO, and the appropriate NATO body can then vote to accept the 5P SNR(A) work.

Policy Development Support

The JTAPIC Program provides support to the US military and government in the development of a variety of policy documents. The Army G-2 asked the JTAPIC Program to provide a section on JTAPIC to be included in the update to Army Regulation (AR) 381-11, "Intelligence Support to Capability Development." JTAPIC will continue to work with the Army G-2 to ensure the JTAPIC Program is included in AR 381-11.

The JTAPIC PM met with the Director, Medical Preparedness Policy, NSS, and the Office of Science and Technology Policy, the White House, to identify how JTAPIC could assist their efforts in writing policy regarding PPE and injury mitigation for first responders. The JTAPIC Program will collaborate regarding injury patterns.

Helmet-Mounted Sensor System

The PEO Soldier-led Gen II HMSS is intended to serve warfighters as a state-of-the-art data collection system that can be used in both operational and training environments. The Gen II HMSS, which will be mounted on the inside crown of a Soldier's ACH, will record blast pressure, and linear and rotational acceleration. See Chapter 4 for more on efforts to develop monitors of blast exposure and the HMSS effort.

Urogenital Protection

The JTAPIC partnership contributed to the development and fielding of a pelvic protection system (PPS) that provides two levels of protection for the pelvic region. The purpose of the PPS is to mitigate femoral artery and urogenital injuries sustained by dismounted warfighters in the vicinity of IED blasts. The PPS consists of a Tier I Protective Under Garment (PUG) and a Tier II Protective Outer Garment (POG) (**Figure 3-5**). The PUG is worn next to the skin and provides protection of the pelvis, femoral arteries, and lower abdominal organs in ground-based blast or fragmentation events (e.g., from IEDs). The PUG also reduces the penetration of dirt and fine debris into a wound area to help prevent infections. The POG is a ballistic system that is worn over the flame-resistant Army combat uniform trousers and provides fragmentation protection for the pelvis, femoral arteries, and lower abdominal organs as well as protection from penetration of dirt and fine debris into a wound area.

Product Manager Soldier Protective Equipment (PM SPE) has continued to evaluate and improve the PPS through the execution of multiple user assessments combined with in-theater US Army Test and Evaluation Command (ATEC) Forward Operational Assessments (FOA). FOA Team 18 recently published the final report of assessments conducted in early 2012 during OEF, which clearly showed that the PPSs were indeed preventing serious injuries to the pelvic region and saving lives. PM SPE also directed and resourced the US Army Aberdeen Test Center (ATC) to evaluate the performance of various POG and PUG designs. Several shock tube and blast events were performed at ATC to evaluate the performance of various vendors of the POG and PUG. ATC personnel worked closely with

POG PUG

Figure 3-5. Examples of a POG and a PUG

the PM SPE and an Army Explosive Ordnance Disposal (EOD) Sergeant flown from a deployment in OEF to design a realistic test scenario for the equipment.

Product Manager Soldier Protection and Individual Equipment (PM SPIE) is working with the JTAPIC team to receive casualty assessments to further understand the effects of blast events on PPSs. PM SPE continues to leverage all Soldier input, feedback, and ongoing PPS assessments along with working with industry to ensure the constant evolution and incremental improvements of pelvic protection and to improve the overall user acceptability and rate of wear by reducing the aerial density and weight, while striving to improve ballistic performance. JTAPIC research validated that PPSs reduce minor to moderate urogenital injuries as well as secondary complications of more severe injuries.

The Army Wounded Warrior Interview Process

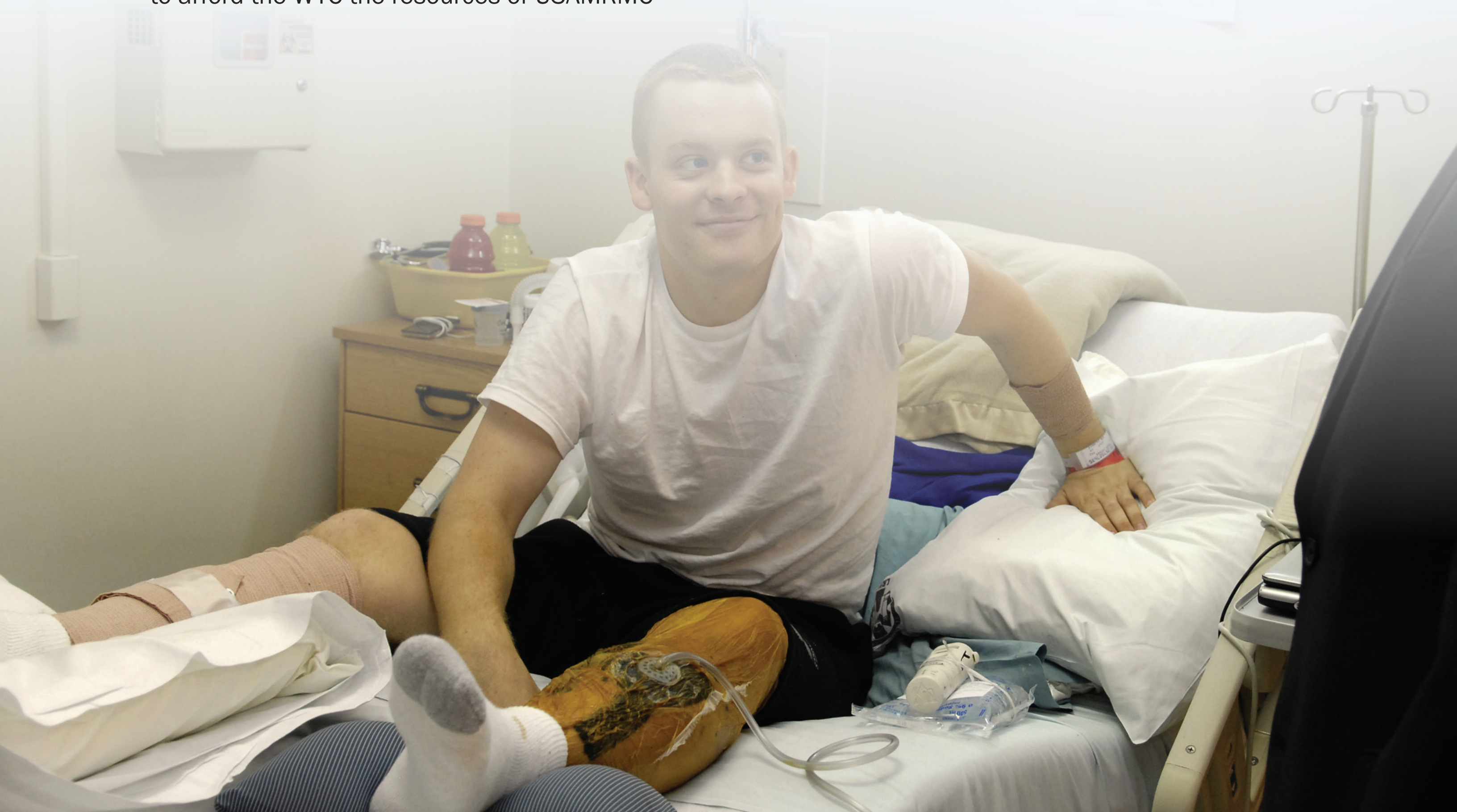
This JTAPIC Program conducts interviews with wounded warriors to gain critical insight into specific mounted and dismounted combat casualty events in theater. The information gained from these interviews provides an in-depth understanding of how Soldiers are being injured and killed on the battlefield. This information fills gaps and validates existing reports on casualty-producing combat events for the intelligence, medical, and materiel communities. The knowledge gained helps develop better ways to protect and treat our wounded warriors.

In FY12, JTAPIC conducted wounded warrior interviews at the Walter Reed National Military Medical Center (WRNMMC); the Naval Medical Center, San Diego; the San Antonio Military Medical Center; and the Fort Hood Warrior Transition Brigade. The JTAPIC dismounted case study reviews and wounded warrior interviews revealed a possible materiel and/or educational issue with a specific electronic countermeasure (ECM) that has rendered the ECM inoperable in certain instances. The absence of this enabler may possibly have contributed to casualties. A solution was awarded for both the US Marine Corps (USMC) and the Army, but not all units have received the new fielding.

On January 24, 2012, the Principal Assistant for Research and Technology, USAMRMC, hosted the Warrior Transition Command (WTC) Surgeon, to explore opportunities for collaboration and to afford the WTC the resources of USAMRMC to assist in screening requests for access to wounded warriors. The JTAPIC PMO provided information on the value of its wounded warrior interview program. Currently, each Warrior Transition Unit (WTU) is approached and dealt with as an independent entity. By coordinating the efforts of JTAPIC through the WTC, we hope to gain access to a greater number of WTUs and avoid the recurring validation needed to speak to wounded Soldiers. The JTAPIC Program will continue to coordinate with WTUs at all levels throughout the continental United States (CONUS) to conduct interviews with warriors in transition.

Battlefield Vehicle Forensics Team (BVFT)

BVFTs continue to be a critical asset of the JTAPIC Program's congressionally mandated mission to improve the understanding of vulnerabilities to threats and enable the development of improved TTPs, requirements, materiel solutions, models, and policy to prevent and mitigate warfighters' injuries. The Anti-Armor Analysis Program (AAAP) at the US Army National Ground Intelligence Center's (NGIC) mission is to investigate all attacks on US vehicles worldwide to establish the



type of weapon used, the weapon's lethal effect, and possible ways to mitigate the weapon's effect. The AAAP leverages a wide range of data sources and collection means, including the forward-deployed BVFTs. These small teams, made up of personnel with extensive maintenance and intelligence backgrounds, are stationed in-country or make periodic short-term deployments. They conduct detailed, hands-on collection of data from battle-damaged vehicles as close to the time and location of the incident as possible—data that are often the key to understanding incidents of high interest.

Responding to Requests for Information

To date, the JTAPIC Program has processed more than 540 RFIs from various customers throughout the DoD. These range from specific information on single incidents to complex analyses. Because this information and analyses can reflect vulnerabilities and performance capabilities, many of the RFIs are handled within a classified setting. A few examples of the types of RFIs include:

- **Assessment of Category "A" Medical Evacuation (MEDEVAC) Casualties.** LTG Michael Barbero, Director, JIEDDO, tasked JIEDDO's Operations Research and Systems Analysis (ORSA) Branch to determine the cause for the rise in the proportion of Category "A" MEDEVAC casualties per successful IED attack. Responding to their request for assistance, JTAPIC's Dismounted Incident Analysis Team (DIAT) provided JIEDDO's ORSA Branch with a preliminary assessment on April 6, 2012, by matching operational context information to initial injury classifications in addition to MEDEVAC casualty status. For dismounted casualties, the trend appeared to be associated with shifts in IED initiation types.
- **Forensic Analysis of Combat Casualty Data.** The JTAPIC Dismounted Working group met to discuss forensic analysis findings on seven casualty-producing combat events. Analysis products reviewed were: gunshot wound analysis, injuries, and any evidence recovered such as fragmentation, ballistics, and PPE associated with the casualty. An integrated analysis product examined casualty data to determine trends in injuries with respect to the operational context.
- **Blast Injury Standards Development.** The Naval Health Research Center (NHRC) performed an analysis to determine the percentage of blast injuries by injury type for the period of January 2010 through November 2012 for both mounted and dismounted WIA Service members. The purpose was to provide results to the Blast Injury Research PCO, USAMRMC, and the JHU/APL to assist in identifying and prioritizing the development of needed blast injury standards based on real-time injury data. The analysis matched blast events to injured Service members and defined injuries using the Abbreviated Injury Scale (AIS) anatomical scoring system and select International Classification of Diseases, Ninth Revision codes for specific body areas in specific body regions. This analysis used injury data provided by NHRC and event data provided by the NGIC and the DIAT.
- **Dismounted Troops Spacing.** As a result of the JTAPIC combat analysis network, ARL saw a need to characterize the vulnerability of the dismounted warfighter from the homemade

explosive threat. Findings confirmed that the leading energetic mechanism causing lower limb loss in dismounted troops is attributable to accelerative loading through the lower leg from the ground and subsequent whole-body translation. ARL quantified the lower limb injury potential using human leg surrogates. Fractures in the surrogate from a buried blast event indicate that the probability for limb loss is nearly nonexistent outside the crater and extremely high inside the crater. This information is critical for specifying standoff distances for troop formations and those using counter-IED devices as a function of crater sizes witnessed in their given area of operations. This information was provided to the DIAT and PEO Soldier.

- **Green-On-Blue Incidents.** The JTAPIC DIAT provided analysis products on Green-On-Blue incidents for the US Army Asymmetric Warfare Group (AWG) focusing on the complex ideological and cultural differences between Afghan nationals and the International Security Assistance Forces. The AWG is using the products to assist in training pre-deploying units. The analysis provided units with better situational awareness and an understanding of the dynamics of interacting with the Afghanistan National Security Forces.
- **Gunshot Wound Analysis.** The JTAPIC partners met with the Marine Corps Operational Test & Evaluation Activity (MCOTEA), the Enhanced Combat Helmet (ECH) Program Office from Marine Corps Systems Command, and USMC Requirements to discuss a JTAPIC Gunshot Wound Analysis product to inform their decision cycle regarding helmet design. The analysis provided the general breakdown of Army/Marine Corps casualties from Small Arms Fire (SAF) by month, region, and engagement ranges; trends in entrance wound locations; correlation of entrance wound locations with PPE damage; and identification of the SAF threat recovered from KIAs. The analysis helped MCOTEA determine if an increase in capability of the ECH was needed.
- **Analysis of Fragments from IEDs Removed from Dismounted Soldiers.** ARL performed an analysis of fragments from IEDs embedded in KIA Service members during events from August 2006 through December 2011. Removed during autopsy by the Armed Forces Medical Examiner System (AFMES), the fragments are transferred to ARL for physical and elemental analysis. ARL sterilizes, photographs, and records the mass, dimensions, and density of each fragment. ARL also provides an elemental analysis using scanning electron microscopy-energy dispersive X-ray spectroscopy, examining a representative population of fragments received. ARL analyzed the mass distribution, recovery location, and elemental composition of the fragments to characterize the IED fragmentation striking dismounted Service members. Of the five fragment categories—ball bearings, bullets, improvised projectiles, Service member equipment, and earth/organic material—ball bearings were the most prevalent, followed by improvised projectiles. The most common weight for ball bearings recovered was 1 gram. Improvised projectiles and pieces of the threat itself were found to have the largest mass. Eighty percent of improvised projectiles and 90% of earth/organic material fragments fall within the fragment sizes used for body-armor testing.

Across all fragment categories, the greatest number of fragments was recovered from the torso and lower extremities.

- **Evaluation of US Service Member Blast Lung Injury Risk.** PM SPIE performed an analysis of all Service members who suffered blast lung injuries in OEF and OIF. The analysis looked at damaged PPE recovered from theater and the possible effects of PPE configuration on blast lung injuries of mounted and dismounted Service members. Input was provided by the DIAT, the AFMES, and the USAISR Joint Trauma System.
- **Analysis of Forearm Protective Material.** The USMC Program Manager Infantry Combat Equipment (PM ICE) requested that JTAPIC conduct an analysis of the feasibility and potential benefit of placing protective material on the forearms of its Marines. The JTAPIC analysis was presented to PM ICE, Marine Corps System Command, and the Marine Expeditionary Fire Squad. The NHRC provided specific injuries from the OEF conflict. ARL analyzed the current threat of fragments impacting the arms and conducted M&S to determine the effect of forearm injuries on required battlefield tasks. PM ICE requested further analysis using this same methodology to determine the area and level of protection to impact for the next generation of Marine Corps body armor.
- **OEF Upper Extremity Analysis for Dismounted Service Members WIA.** This analysis by ARL evaluated the benefits of adding forearm protection for dismounted infantrymen. First, an analysis was conducted on combat evidence recovered from the upper extremity of dismounted Service members during autopsies performed by the AFMES. The analysis determined the mass distribution and predominant elemental composition of the upper extremity fragments to gain a better understanding of the threats this new armor would need to mitigate. Next, the Operational Requirement-based Casualty Assessment personnel model was used to evaluate the potential injury and human performance effects from fragments similar to those recovered by AFMES. Finally, an analysis was conducted of dismounted theater data for Army and Marine Corps Service Members WIA in OEF from January 1, 2009 to September 12, 2011 to determine the number, location, type, and severity of injuries to the forearm, as well as the entire upper extremity. The investigation of physical evidence, M&S of injury and operational significance, and analysis of WIA injury data, allowed ARL to perform a comprehensive evaluation of the benefit of forearm materiel protection.

JTAPIC RFI submissions are available via the RFI Management System of the Distributed Incident Collaboration Environment. In collaboration with ARL, this system allows customers to log in to submit RFIs as well as see products being developed in real time by the JTAPIC Program partnership on a daily basis. This website enables the JTAPIC Program to establish two-way communication with outside DoD and government agencies on both classified and unclassified networks, and it also provides the capability to track tasks and RFI status in support of submissions, which are then traceable back to individual JTAPIC Program partners. The RFI system is located at http://jtapic.arl.army.mil/dice.

Key Accomplishments

The JTAPIC Program has already made a difference in the way warfighters are protected from blast-related injuries. For example, the program has established an effective, near real-time process for collecting and analyzing data from blast-related combat incidents. Using this process and sophisticated fragment analysis procedures, the program was able to confirm the presence of prominent threat weapons of interest to the intelligence community. As the US continues to conduct full-spectrum operations, it is important to capitalize on opportunities to quickly identify weaknesses and vulnerabilities through incident analysis and pattern analysis to adjust our TTPs and upgrade vehicles and protective equipment to reduce injury and save lives. Enhancing the warfighters' ability to adapt more quickly will maintain their tactical advantage on the battlefield.

A sampling of JTAPIC-related materiel and non-materiel improvements is shown in **Table 3-3**, while more detailed program accomplishments are presented in the following paragraphs.

Determining Injury Patterns in Mine Roller-Equipped MRAP Vehicles

Within the JTAPIC partnership, the NHRC collaborated with the AFME and the NGIC in a study identifying injury patterns and injury severities of Service members injured in MRAP vehicles equipped with mine rollers. The objective of the study was to assess frequency and survivability of this MRAP vehicle variant. NHRC provided casualty data on 327 injured Service members. Results of the study revealed injury trends for multiple strike points on the vehicle, severity of injury by strike point, and types of wounding patterns sustained in this vehicle variant. Vehicle incidents involving mine roller equipment were divided into three groups: Off-Set group, Side-IED group, and Under-Body IED group. The AIS (**Figure 3-6**) was used to compare injuries across the three groups. The researchers found that, regardless of group, the majority (61%) of the injuries were at the

Table 3-3. Examples of JTAPIC Advances That Benefit the Warfighter

Materiel Improvements
• Stryker Driver Enhancement Kit due to specific crew injury patterns. • Bradley Urban Survivability Kit due to injury patterns associated with underbelly munitions and fires. • Stryker Double V Hull due to comparison between Live-Fire Test & Evaluation (LFT&E) and theater injury patterns, especially for the driver area. • Improved seats and independent suspension for theater vehicles. • Improved underbody known as the Caiman Multi-Theater Vehicle.
Nonmateriel Improvements
• Review of BECIR and associated EHRs with CENTCOM is improving identification, tracking, treatment, and management of exposed Service members. • Sensor data analysis review with sensor proponent and CENTCOM is helping to identify Service members exposed to a potentially concussive event. • Theater data re-evaluated the need for live-fire testing, which resulted in cost savings by canceling unnecessary tests. • Conducted experiments with homemade explosives, quantifying fragment velocities and characterizing the blast, to validate optimal within-patrol intervals. • Developed a visualization tool (Visual AID) that can anatomically map injury, which improved the quality and efficiency of analytical products.

AIS	Injury
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximal

The AIS is an anatomical scoring system in which each injury is classified according to its relative importance on a 6-point ordinal scale (1 = minor injury through 6 = maximal injury).

Figure 3-6. Abbreviated Injury Scale (AIS)

AIS 1 level. Notably, the Side-IED group had a smaller proportion of injuries classified as AIS 3 or greater (1.4%) compared to the Off-Set group (21.5%) and the Under-Body IED group (6.3%).

Analyzing Real-Time Casualty Data

The NHRC provides a weekly analysis of combat casualties for all mounted and dismounted WIA Service members in Overseas Contingency Operation (OCO) to the JTAPIC PMO. The WIA event details are gathered from various operational databases, including Combined Information Data Network Exchange, Significant Action Reports, Medical Situation Awareness in Theater, and Defense Casualty Information Processing System. Each medical record of a WIA Service member is thoroughly reviewed to find all pertinent injury information, which is then coded by severity of injury in the standard AIS coding methodology by AIS-certified registered nurses. In addition to injury analyses conducted at NHRC, these de-identified AIS-coded WIA profiles are then made available to the JTAPIC partnership for additional analysis (e.g., vehicle live-fire and testing analysis, which impacts vehicle design and modification to preserve life and limb) as well as to various body armor material developers. Because of the common requirement for medical data, NHRC participates in nearly every JTAPIC partnership analysis. The NHRC has provided DoD with 4,608 detailed clinical profiles of casualties injured in OCOs. In addition, 934 casualty medical records were reviewed by NHRC medical staff for compliance with directives associated with the BECIR for current theater operations.

Analyzing Soldier Injury Data

Within the JTAPIC partnership, the NHRC assisted the US Army Soldier Requirements Division in examining improvements made to Soldier protective equipment and the effects those improvements have had on Soldier survivability and injury mitigation. NHRC analyzed the distribution, frequency, mechanism of injury, and severity of combat injuries to Soldiers KIA. Injury data were reviewed by body region (head, neck, face, thorax, abdomen, pelvic, upper extremities, and lower extremities) and were organized by year (2010 and 2011). The researchers found few differences in the distribution of injuries between the two years studied for Soldiers KIA. They found that the largest number of injuries in 2010 were equally divided between the head and thorax (19%). In 2011, the thorax had the largest proportion of injuries, followed by the head. The researchers observed changes in the type and severity of lower and upper extremity amputations from 2010 to 2011. They found that the percentage of AIS 3+ lower extremity amputations due to blast decreased by 8% during this period. In 2010, there were 13 lower extremity amputations that were AIS 5, while in 2011 there were no AIS lower extremity amputations greater than 4. In 2010, over half of lower extremity amputations were at or above knee, below hip amputations, and in 2011, the amputations were primarily below knee at or above ankle amputations. Regarding the upper extremity, amputations in 2010 were mostly at or above the elbow but below the shoulder, but in 2011 they were primarily below the elbow but at or above the wrist and to the fingers. NHRC continues to work on the companion piece for Soldiers WIA and may also complete this work for additional years (e.g., 2009 and 2012).

Determining Casualty Injury Trending Through a Tri-Service Database

The NHRC has been tracking each casualty injured in OCO since the beginning of OIF/OEF. Over time, this capability has evolved into a database that includes all Service members injured during deployment. This tri-Service capability, resident at the NHRC, is the Expeditionary Medical Encounter Database (EMED).Each casualty that occurs in OCO is identified within 7 days of injury, coded by diagnoses and injury severity scores, and entered into the EMED for analysis. During FY12, NHRC trended a number of sentinel injury types common during OCO, including TBI, amputations, urogenital injury, facial injury, and complex blast injury. This quarterly report of sentinel injuries occurring in theater alerts DoD leadership to spikes in occurrence rates. Such capability allows DoD leadership to focus investigations on trends that represent a meaningful change in the running average of that injury type over time, saving precious resources and aiding in determining the causes for increased injury risks to our Service members in theater.

Key Coordination Efforts

NGIC Small Arms Team

In October 2011, JTAPIC conducted a meeting with the Small Arms Team at the NGIC to engage and formalize the team in the identification process of ballistic material recovered by the AFMES during autopsy of Soldiers KIA. This process will fill intelligence gaps and identify small arms weapon types being utilized in theater. The recovered evidence, along with the analysis product, will be transferred to ARL's Survivability/Lethality Analysis Directorate (SLAD) for further nondestructive analysis and secure storage.

Combined Joint Task Force (CJTF) Paladin

Representatives from JTAPIC and the MOM and CCC Research Programs met with COL Leo Bradley, Commander, CJTF Paladin (responsible for counter-IED efforts in Afghanistan) to explore enhanced collaboration and communication opportunities. COL Bradley wanted a more active role with JTAPIC to include enhanced forensic training for his EOD teams for post-event analysis, partnering with NGIC in completing event report content, and access to JTAPIC product reports to integrate lessons learned and establish an archive of data analysis products. JTAPIC provided its information products and gave CJTF Paladin access to JTAPIC data. In exchange, JTAPIC received access to CJTF Paladin data.

Mounted Combat Data Working Group Meeting

The JTAPIC partners co-hosted a Mounted Combat Data Working Group Meeting sponsored by the Foreign Intelligence Directorate on January 24–26, 2012. The topics discussed included current threats in theater, future threat weapon information, vehicle vulnerability to threats, and mitigation strategies.

Ground Vehicle Survivability and Occupant Protection (GVS&OP) Educational Program

In March 2012, JTAPIC participated in the Naval Postgraduate School, Center for Survivability and Lethality, meeting for the development of a new educational program in GVS&OP to develop and disseminate educational products contributing to the continued development of GVS&OP as a formal design for US military ground vehicles. Representing the Service branches in collecting and analyzing data, JTAPIC produces customized products reflecting information with a true operational context and supports this effort by providing examples of vulnerability assessments of ground vehicles.

Way Forward

The JTAPIC partnership will continue to collaborate with and provide actionable information to vehicle program managers and TRADOC capability managers to assist with force modernization decisions. In addition, JTAPIC will continue to provide targeted analysis and information in response to specific RFIs from DoD customers to help guide decisions.

Chapter 4

Predicting Injury and Monitoring Blast Exposure

Understanding the blast environment and injury risks that Service members are exposed to is critical to providing the best protection to avoid injury and the best treatments should injuries occur. This knowledge aids COCOM and medical personnel in decision making, informs equipment design, and guides protection technology and research investments. The PCO and JTAPIC Program are involved in several efforts to increase this knowledge base and inform stakeholders, including: (1) a process to evaluate standards used in blast injury prevention efforts, (2) an initiative to collect blast exposure data during combat, and (3) a roadmap for the development of a computational model of non-impact, blast-induced mTBI.

Blast Injury Prevention Standards Recommendation (BIPSR) Process

DoDD 6025.21E assigns to the EA the responsibility to "Provide medical recommendations with regard to blast-injury prevention, mitigation, and treatment standards to be approved by the ASD(HA)." The PCO advises the EA on the MHS Blast Injury Prevention Standards to recommend to the ASD(HA). These standards can range from simple dose-response curves and injury thresholds that address single components of blast insults (e.g., peak force) to complex algorithms and models that address multiple components of blast insults (e.g., force-time history).

The MHS Blast Injury Prevention Standards play a critically important role in the prevention of warfighter injuries and the enhancement of warfighter survivability by informing health hazard assessments, survivability assessments, and protection system development aimed at producing safe weapon systems, survivable combat platforms, and effective protection systems (**Figure 4-1**). While it is the EA's responsibility to identify and recommend standards, it is important to note that there are three communities that must participate as partners in the development of a standard: the medical research, test and evaluation, and materiel development communities (Figure 4-1).

The test and evaluation community, and materiel developers are often presented with standards from various sources and with varying states of biomedical validity. They often rely on the opinions of single SME organizations regarding the best available standards. An unbiased and inclusive process is needed, in which a broad community of SMEs is recruited to identify and thoroughly assess the biomedical validity and applicability of medical standards to DoD-unique problems. Likewise, a process is needed for approving Blast Injury Prevention Standards so that the DoD can ensure consistent application of the best available standards.

BIPSR Process

The BIPSR process is an unbiased, inclusive, stakeholder-driven process for identifying and assessing MHS Blast Injury Prevention Standards that support weapon system health hazard assessments, combat platform occupant survivability assessments, and protection system development. The PCO developed the BIPSR Process to support a key EA responsibility to recommend Blast Injury Prevention Standards for approval by the ASD(HA). The medical, test and evaluation, and materiel development communities have been actively involved in the development and application of this process. There are two key components in the process to identify and approve an MHS Blast Injury Prevention Standards:

- **Recommendation Process.** An unbiased and inclusive process, under the authority of the EA, for identifying and thoroughly assessing the MHS Blast Injury Prevention Standards with a focus on biomedical validity and applicability. This process reaches out to a broad community of SMEs in the DoD, other federal agencies, academia, industry, and other nations.
- **Approval Process.** A formal process for advising the EA on the MHS Blast Injury Prevention Standards to recommend to the ASD(HA) for approval and DoD implementation.

Figure 4-1. The MHS Blast Injury Prevention Standards for Safe Weapons, Survivable Combat Platforms, and Effective Protection Systems Are Developed with the Aid of the Medical Research, Test and Evaluation, and Materiel Development Communities

The PCO contracted with the JHU/APL, a University Affiliated Research Center and DoD-trusted agent, to serve as an independent agent to develop and execute the BIPSR Process. Key characteristics of the BIPSR Process include:

- Involvement of stakeholders from the test and evaluation, materiel development, medical, and operational communities, who remain active throughout the process
- SME panels that are broad-based, nonadvocacy groups composed of individuals from academia, industry, DoD, and other federal agencies
- Consensus building to recommend the best, biomedically valid standards that meet the needs of the DoD stakeholders
- Identification of gaps and research needs when suitable standards do not exist

The major pillars of the BIPSR Process include (1) reviewing existing capabilities through a systematic literature survey, (2) developing data collection mechanisms, (3) developing evaluation criteria, (4) evaluating candidate standards, (5) holding a consensus-building meeting for stakeholders to share information, (6) deriving and executing scenario-based test cases and executing the tests for the identified candidate standards (where applicable), and (7) developing recommendations for the MHS Blast Injury Prevention Standards and evaluating the process.

Stakeholder Meetings

During FY12, the PCO sponsored and chaired two BIPSR Process stakeholder meetings. The first Stakeholder Meeting was held at JHU/APL in Laurel, Maryland. Meeting goals were to review the proposed BIPSR Process and seek stakeholder feedback to enhance its efficiency and value to the DoD. Representatives from the medical, test and evaluation, and materiel development communities and all Services participated as stakeholders in this meeting. Stakeholder recommendations dealt primarily with the broader application and policy issues leading up to and following implementation of the BIPSR Process (e.g., injury type selection, breadth of stakeholder representation, and the process by which the ASD(HA) will codify a Blast Injury Prevention Standards). Based on the stakeholders' recommendations, it was concluded that the overall BIPSR Process is structurally sound and that the underlying mathematical methods and process flow do not require modification.

The second Stakeholder Meeting was held at JHU/APL to determine the first two Blast Injury Prevention Standards to undergo BIPSR Process review. Representatives from the medical, test and evaluation, materiel development, and operational communities across the DoD participated as stakeholders in this meeting. The stakeholders reviewed the proposed topic prioritization process and offered suggestions for process improvements. To address the meeting goal, JHU/APL developed a prioritization methodology to identify which Blast Injury Prevention Standards should be reviewed by the BIPSR Process (**Figure 4-2**). The methodology relied on several key components, including:

- **Blast injury types** for which Blast Injury Prevention Standards would be developed. The proposed blast injury type list to be prioritized was based on the Technical Report, "Medical Evaluation of Non-fragment Injury Effects in Armored Vehicle Live Fire Tests: Instrumentation Requirements and Injury Criteria," Walter Reed Army Institute of Research (WRAIR), September, 1989.
- **Evaluation factors** that provide the means for the stakeholders to assess the relative criticality of the blast injury type in terms of such issues as frequency of occurrence, impact on readiness, and resource requirements.
- **State tables** that provide the stakeholders with an objective basis for rating the blast injury types. A "grade" is given based on pre-agreed-upon state definitions or levels, thus removing unintended bias.
- **Weighting values** that allow the assessment to emphasize characteristics and/or evaluation factors that are more critical.

Due to the stakeholders' concerns related to the categorization of blast injury types as well as the defined factors and associated state (level) definitions, the meeting agenda was revised to build stakeholder consensus on the blast injury types, evaluation factors, and state table definitions to be used for a downstream prioritization exercise. The PCO and JHU/APL are currently making the process improvements that were suggested by the meeting stakeholders.

Testing the BIPSR Process – Toxic Fire Gas Inhalation (TGI) Exemplar

The viability of the BIPSR Process was tested using TGI as an injury domain exemplar. TGI was selected as the exemplar because it would allow the focus of the effort to remain on the evolution of the process rather than on the complexities of the insult. Assessment of the BIPSR TGI exemplar focused on injury prediction tools that determine injury and performance outcomes from inhalation exposure to mixed gases. These tools could be used to assess warfighter survivability in combat vehicles, ships, aircraft, or enclosures where inhaled gases may be a threat and to assess warfighter health risks associated with the use of weapon systems that produce toxic gases.

The TGI exemplar served to verify the BIPSR Process. It also provided a set of lessons learned that will serve to enhance future BIPSR Process implementations. Lessons learned included:

- Engage the stakeholders early in the process to identify the models currently in use, their needs/intended uses, and the test cases the stakeholders want to see analyzed.
- Issue an RFI to locate all potential resources that will address the defined needs/intended uses.
- Conduct more frequent face-to-face, teleconference, or web meetings between the SME panel and model owners.
- Involve users and stakeholders in the testing process.

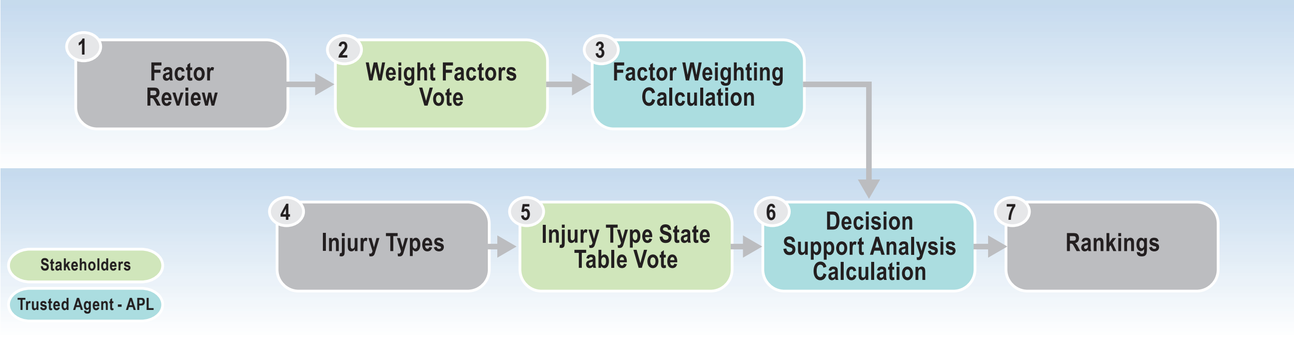


Figure 4-2. Blast Injury Type Prioritization and Selection Methodology

These lessons learned will be incorporated into the BIPSR Process to enhance subsequent implementation and resulting products.

Developing Computational Models of Non-Impact, Blast-Induced Mild Traumatic Brain Injury

The current understanding of the existence and mechanisms of non-impact, blast-induced mTBI is very limited. There are numerous hypotheses of the mechanisms of brain injury caused by blast exposure to the head including: blood vessel tearing and hemorrhage, mechanical or immune-triggered breakdown of the blood–brain barrier (BBB), vasospasm, air emboli, microcavitation, diffuse axonal injury, vasogenic and cytotoxic edema, local ischemia/hypoxia, oxidative stress and reactive oxygen species, mechanical misalignment of synapses and synaptic plasticity, calcium ion (Ca++) flooding and neuroexcitation, and deregulated induction of apoptotic and necrotic pathways. The conventional approaches of in vitro study, animal testing, and analysis of clinical data are useful and necessary, but these are slow, expensive, and often nonconclusive, thus limiting the availability of tools for the rapid evaluation of various blast-related mTBI injury hypotheses. Physiology-based mathematical modeling tools of blast-induced head injury may provide a framework to guide experimental testing, interpret data, and scale animal data to humans in the effort to elucidate injury mechanisms and determine the effectiveness of protective or treatment strategies.

Until very recently, high-fidelity computational modeling of blast-related brain injury has not been studied. Modeling blast mTBI and resulting trauma is extremely difficult as it involves a range of disciplines, including gas and structure dynamics, biomechanics, physiology, pathology, biology, biochemistry, and time and space scales. In recent years, considerable progress has been made in DoD-sponsored models. Most of these efforts are unique and represent novel distinct approaches. However, existing software tools and computational models of TBI still have numerous limitations, and some major challenges remain to be solved in blast wave brain TBI models.

The DoD Blast Injury Research PCO, in coordination with the DCoE, hosted the first International State-of-the-Science Meeting on Non-Impact, Blast-Induced Mild Traumatic Brain Injury on May 12–14, 2009, to critically examine research focused on the relationship between non-impact, blast exposure and mTBI, and to review proposed injury mechanisms. Based on the findings and recommendations from this meeting, the DoD Blast Injury Research PCO established the DoD Brain Injury Computational Modeling Expert Panel, which brings together SMEs from the engineering, medical research, blast physics, and clinical medicine communities to:

- Assess the state-of-the-art in computational modeling to understand the injury mechanism of blast-induced mTBI
- Integrate ongoing DoD research efforts
- Leverage ongoing efforts by other organizations (Department of Transportation, NIH, etc.)
- Accelerate the transition of preventive and treatment strategies

The PCO anticipates that this focused effort will be the first step in leveraging and integrating results of individual projects to generate a unified solution that may result in development and validation of one or more accurate computational models of blast-induced mTBI. These models would expedite prevention and treatment strategies for blast-related mTBI by providing a framework for understanding injury mechanisms, guiding experimental testing, interpreting data, and scaling animal data to humans. Through a series of five focused meetings, which included presentations by SMEs and workshop sessions that covered specific computational modeling challenges, the Expert Panel has developed a roadmap for research.

Summary of Expert Panel Meetings

At the first Expert Panel meeting in March 2010, participants developed a working definition of a validated computational model of non-impact, blast-induced mTBI. They also developed a list of challenges to be addressed at future meetings. At the second Expert Panel meeting in August 2010, participants focused on reviewed computational modeling efforts at the cell, tissue, and organ levels aimed at understanding the injury mechanism of non-impact, blast-induced mTBI.

The third meeting of the Expert Panel, held in December 2010, focused on reviewing animal modeling, Department of Transportation modeling efforts, epidemiology of blast injury, and clinical aspects of mTBI. At the fourth Expert Panel meeting in March 2011, participants focused on reviewing soft tissue modeling, biomechanics, and related challenges, such as solving brain biomechanics equations using finite element models (FEM) solvers for soft tissue.

The fifth meeting of the Expert Panel, held in September 2011, focused on synthesizing the information gathered at the first four meetings in an effort to develop a consensus roadmap for a validated computational model of non-impact, blast-induced mTBI. Prior to the meeting, the Expert Panel was divided into four groups, with each group simultaneously developing a computational roadmap approach. The Expert Panel reviewed each of the four approaches at the meeting and made recommendations toward an integrated approach. After the meeting, the DoD Blast Injury Research PCO drafted an integrated roadmap that incorporated the approaches and recommendations of the Expert Panel. Notably, the Expert Panel will continue to serve as an advisory panel to the government, at least until a validated computational model of non-impact, blast-induced mTBI is achieved.

Computational Modeling Research Roadmap

Physiology-based computational/mathematical modeling tools of blast head injury may provide a framework to understand injury mechanisms, guide experimental testing, interpret data, and scale animal data to humans to study both blast wave TBI mechanisms and the effectiveness of protective or treatment strategies. Computational modeling of non-impact, blast-induced mTBI is very difficult, involving a range of disciplines (e.g., biomechanics, physiology, and biology), lengths (subcellular to macroscopic), and time scales (microseconds to weeks). Validated multidisciplinary models are needed that integrate blast explosion physics, anatomical- and image-based human body geometrical models, human body biodynamics, tissue biomechanics, and several physiological models. Overall, data from the engineering/physical world have to be united with data from the medical world.

Key aspects of developing the model will include characterizing blast injuries; developing models at the in vitro, animal, material, and human levels; and correlating with the blast insult, damage/injury, and clinical data/observations. Currently, there are a number of key questions that will need to be studied before an integrated model can be proposed for non-impact, blast-induced mTBI. Aspects of the research roadmap are shown in **Figure 4-3**.

An enterprise approach is envisioned to achieve these objectives. The enterprise (depicted in **Figure 4-4** next page) will serve to (1) set priorities, (2) integrate research, and (3) create a framework for sharing. The structure will consist of CoEs, a Program Integrator, and a national database/repository. The Program Integrator will coordinate data flow between the CoEs and will ensure quality and control the database. The CoEs will involve teams of researchers from a variety of fields, including blast physics, biomechanics, materials, biology, engineering, and medicine. The goals of the enterprise are to set the broad research agenda and prioritize specific research challenges, set a framework for the sharing of information and resources, provide quality assurance, minimize duplication and free resources for novel research, keep the work focused on the solution, and evolve with the research.

Blast Monitoring Systems

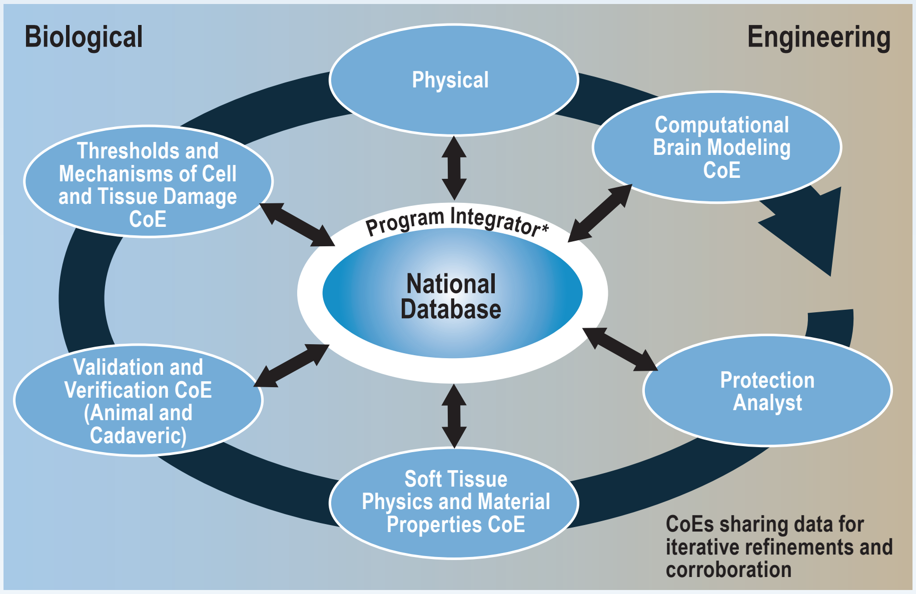
Helmet-Mounted Sensor Systems

PEO Soldier's PM SPE fielded the Gen I HMSS to two deploying brigade combat teams between December 2007 and February 2008. Additionally, the Marine Corps' PM ICE fielded the Gen I HMSS to two deployed Marine battalions. The HMSS recorded helmet acceleration and pressure from impacts and explosions. The JTAPIC Program, in partnership with PM SPE and PM ICE, led a three-phased HMSS data analysis project. It demonstrated the ability to link sensor, operational, and injury data using established JTAPIC processes, and it demonstrated the ability to translate helmet sensor data into meaningful head "doses" using a mathematical model.

Data obtained from Gen I HMSS fielding led to improvements in the Gen II HMSS fielding and data collection plans. The ultimate goal of the Gen II HMSS is to develop a body of knowledge of kinetic events to support the DoD medical community's research on mTBI.

Characterizing Blast Injury	• Measuring and documenting the effects of blast exposure on the human body
Blast Injury Modeling	• Mathematical mapping and computerized simulation of the structural connectivity and biological response in the brain following exposure to a blast wave
Animal Testing and Modeling	• Use of animals (e.g., rats, pigs, and nonhuman primates) in experiments to determine the mechanism and anatomic distribution of injury • Computer simulation of animal tests
Human Surrogate and Material Modeling	• Physical models that typically consist of a skull, brain, facial structure, and skin • Determining the material properties and response for various regions of the brain and relevant interfaces (e.g., skull/cerebrospinal fluid/soft tissue)
Human Simulation and Mathematical Modeling	• Computational simulations of laboratory blast exposure tests to identify variations in pressure, stress, cavitation, etc. • Modeling fluid dynamics and biomechanical data to predict effects on brain regions
Dose-Damage-Outcome Correlation	• Dose-damage-outcome correlation refers to linking external blast exposure to the mechanical dose within the brain to neural damage and to clinically relevant outcomes (e.g., behaviors that are clinically accepted as mTBI)
Clinical Data/Observations	• Clinical data and observations are the information gathered (e.g., neurocognitive, physiological, and behavioral) when humans are exposed to blast

Figure 4-3. Roadmap for Computational Modeling



*Program Integrator coordinates data flow between centers and ensures quality and controls database

Figure 4-4. The Computational Blast-Induced mTBI Modeling Enterprise

The Gen II HMSS, a self-contained transducer, records and stores both linear and rotational accelerations to the helmet and has an added overpressure trigger to detect when Soldiers are exposed to high-energy-induced blast impulse and impacts. It is mounted internally in the crown of the ACH, ECH, or Combat Vehicle Crewman Helmet. It weighs 2.14 ounces and has a 12-month rechargeable battery (**Figure 4-5**). In support of PEO Soldier and PM SPE, the ATC has conducted numerous free field and shock tube blast overpressure tests of the Gen II HMSS. Currently, there are more than 17,000 sensors fielded to 6 brigade combat teams with more than 9,000 of those deployed in OEF. The ATC has conducted first article testing and lot acceptance testing of the system. The JTAPIC Program completed the development of the Gen II HMSS software application early in December 2011 in time for the second wave of helmet sensor fielding in February 2012. The JTAPIC Program worked with PEO Soldier to field the screening software with the first wave of helmet sensors fielded to a unit at Fort Carson, Colorado. This screening software extracts and processes the helmet sensor data as they are downloaded to the data collector's computer. The output is a Red/Amber/Green designation for each recorded impact event. Service members with Amber or Red events will receive command-directed evaluations in accordance with DoDI 6490.11, DoD Policy Guidance for the Management of Mild Traumatic Brain Injury/Concussion in the Deployed Setting. The JTAPIC Program is managing a sensor data analysis project to determine whether the sensor data correlate with events and injuries. In addition, PEO Soldier has organized an Integrated Product Team composed of the medical community, the Army's Rapid Equipping Force, and DARPA to integrate and synchronize current and future sensor development efforts.

Improved Capabilities
✓ 6-axis accelerometers
✓ 12-month battery life

Figure 4-5. Gen II HMSS

The DARPA Blast Gauge

DARPA contracted with BlackBox Biometrics to complete the development of a small, lightweight, and inexpensive blast dosimeter. The DARPA Blast Gauge is used to indicate whether a Soldier has experienced an overpressure event, and can help identify individuals requiring medical evaluation. The gauge measures blast exposure, immediately rates exposure level, and stores data for records and research. The gauge includes overpressure exposure-level status lights (red, yellow, or green, **Figure 4-6**) and can be attached to helmets, gear, or other mounting points on the warfighter.

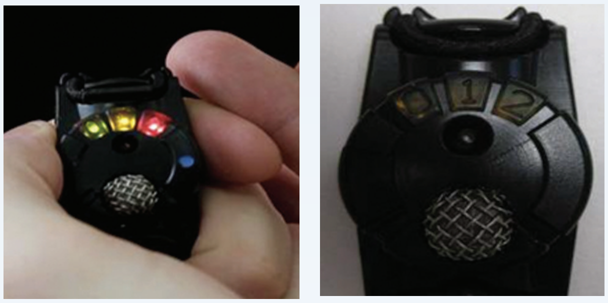


Figure 4-6. DARPA Blast Gauge Overpressure Exposure Level Status Lights

An initial field trial involving three military units with distinct missions in Afghanistan demonstrated the device's reliability and wearability, but there were too few blast incidents to determine its overall effectiveness. Working with other interested combat units in high-risk areas, DARPA provided approximately 130,000 devices as well as training on use and data collection to these units. This trial captured hundreds of individual exposures, resulting in the following key findings:

- Immediate feedback on blast exposures identifies injuries that would have otherwise been missed.
- Overpressure must be measured to capture the primary blast injury.
- Measurements at multiple body locations are needed.
- Exposures can vary significantly for nearby Service members.
- The majority of blast incidents occur during training.

In addition, ATC conducted shock tube and free-field blast testing of the DARPA Blast Gauge in the 1QFY12 for the ATEC release of the *Safety Confirmation and Capabilities and Limitations Report*.

Integrated Blast Effects Sensor Suite Program

The I-BESS Program, a R&D effort sponsored by the Army's Rapid Equipping Force and developed by the Georgia Tech Research Institute (GTRI), was initiated to address the VCSA's concern about TBI.

The I-BESS is an integrated, wireless system for use by both mounted and dismounted Soldiers that measures acceleration and overpressure associated with events that may result in mTBI. It was designed using government-owned and commercially available data-processing architectures and software, making it expandable and upgradeable in the future. The system includes a Soldier Body Unit, which collects blast information on an individual Service member (**Figure 4-7**), and a vehicle system, which contains floor- and seat-mounted accelerometers to collect information on vehicle blast engagements. ATC, in collaboration with GTRI, established communication protocols between the ATEC Black Box and I-BESS to utilize the ATEC-established procedure for storing black box data. Event-driven data collected from the I-BESS are ultimately transferred to the ATEC Black Box system and delivered stateside from in-theater deployments. Access to these data is provided to the JTAPIC Program for inclusion of personally identifiable information and annotation in Soldiers' medical records.

Tests conducted on the I-BESS by ATC included safety confirmation (electromagnetic

Figure 4-7. I-BESS

interference, secondary projectile safety, and ballistic fragmentation), environmental effects such as drop impact and environmental durability (dust and water immersion), and functionality (human factors effects, shock tube blast, free-field blast, and vehicle live-fire blast). ATC also conducted follow-on safety confirmation testing of the Peltor headset, which was added to the Soldier Body Unit portion of the system in December 2012. The Peltor headset features triaxial linear accelerometers and angular rate sensors to capture the kinematics of the human head during a blast event.

Blast Sensor Program

The Marine Corps Systems Command and Marine Corps Warfighting Laboratory, with technical support from the Naval Research Laboratory, conducted an evaluation of current blast sensors for use in combat for triage of individuals exposed to blast. The Marine Corps evaluated the feasibility of the DARPA Blast Gauge and the Army HMSS using controlled overpressure/IED event testing and an evaluation at the Breacher School. End user evaluations with a deploying EOD Company are planned.

The DARPA Blast Gauge is worn in three locations, typically two attached on the front of the Marine and one on the back. The HMSS is mounted in the crown of the interior of the helmet.

During controlled overpressure/IED event testing, the DARPA Blast Gauge generated values in line with the actual conditions but there were issues in understanding how to interpret the values. Sensors exposed to a direct blast wave over-reported the actual pressure due to summing of the primary and reflected blast waves. Sensors mounted away from the direct blast under-reported the pressure because the Marine's body shielded the sensor.

Results from Breacher School evaluation revealed that while DARPA Blast Gauge generated values in line with actual conditions, there were issues with where to mount the sensor on the Marine and how to collect data. The Army HMSS was found to have issues with the time-date stamp reliability and could not map to laboratory-grade accelerometers.

Overall, the Marine Corps reported the DARPA Blast Gauge provided correlatable data to the actual blast exposure but only on one of the three sensors, making interpretation of data in the field difficult. The logistics burden of the DARPA Blast Gauge, with its small sample storage size and 1-month battery life, was also identified as a shortcoming in the EOD evaluation.

In the evaluations, the Army HMSS failed to provide readings that correlated with the effects of the blast. Additionally, the Marine Corps made a decision not to deploy this sensor to theater in FY13 based on its concern that the reduced crown offset due to the placement of the HMSS inside the helmet raised a ballistic safety issue with the helmet.

Due to issues with the currently available sensors, the Marine Corps Systems Command initiated an FY12 SBIR effort to create a blast dosimeter on the EOD vest. The effort includes reducing the logistics burden of the DARPA sensor by increasing battery life and time between downloads, and making the data meaningful to the end user in real time.

The PEO Soldier has conducted ballistic testing on HMSS-equipped helmets and concluded that the HMSS does not present a risk to Service members and does not compromise the ballistic integrity of the helmet. Ballistic testing of the HMSS-equipped helmets has not demonstrated any poor ballistic performance, penetrations or high back face deformations resulting from their tests. PEO Soldier has amassed thousands of valid blast event data points using the HMSS. Integration of the helmet sensor system remains a key item of interest as PEO Soldier moves forward with its future Soldier Protection System and future lighterweight and smaller helmet systems. PEO Soldier has already begun development of a future Integrated Soldier Sensor System that incorporates both the next generation of the helmet sensor along with the next generation of the DARPA Blast Gauge, and it believes this combination in the next generation system will ultimately provide the best correlation of all combat-related traumatic events to actual head injury for Soldiers supporting future deployments.

Chapter 5

Blast Injury Knowledge Gaps – NATO Collaboration

NATO's forces regularly sustain attacks from blasts or explosions by IEDs, land mines, and rocket-propelled grenades. Blast injury has become a significant source of casualties in current NATO operations. Advances in military PPE have allowed individuals to survive blasts that in previous eras of military combat would not have been survivable.

The PCO continues to be involved in collaborative activities with NATO to understand blast injury and translate the scientific discoveries into blast injury mitigation measures. The PCO and NATO members recognized the need to assess the state-of-the-science in the international community regarding blast injury and to facilitate information sharing and collaboration. In October 2011, NATO held the HFM-207 Symposium "A Survey of Blast Injury Across the Full Landscape of Military Science" to address this need. Based on recommendations from the symposium, a new NATO technical activity, HFM-234 "Environmental Toxicology of Blast Exposures: Injury Metrics, Modeling, Methods, and Standards," was subsequently proposed and approved. Both the symposium and the technical activity are described in this chapter.

HFM-207 Symposium: A Survey of Blast Injury Across the Full Landscape of Military Science

Blast injury refers to the broad spectrum of injuries that can result following either direct or indirect exposure to an explosion. Blast-related injury to the brain is particularly complex and presents a significant challenge to medical practitioners who diagnose and treat brain injuries. The HFM-207 Symposium was organized to consider the breadth of science needed to understand blast injury and to provide insight into potential new diagnosis and treatment options for the spectrum of blast injuries presented to NATO medical providers. The symposium had three goals: (1) increase the understanding of blast injury in military operations, (2) explore and describe the range of blast injuries seen in current NATO operations, and (3) delineate some of the medical treatment strategies currently being employed by NATO medical personnel.

The HFM-207 Symposium was held on October 3–5, 2011, in Halifax, Canada. The PCO Director was a co-chair of the NATO Research and Technology Organisation's HFM Panel program committee that organized the symposium. The other co-chair was from the meeting host nation—Chief Scientist, Defence Research and Development Canada-Suffield. The symposium highlighted the need for continued cooperation among NATO countries regarding research on blast exposure. A total of 45 technical presentations (41 scientific session papers and 4 keynote papers) were delivered representing R&D efforts in nine nations (Canada, Czech Republic, France, Georgia, Germany, Israel, Sweden, UK, and United States). Six symposium sessions (see text box) addressed the Program Committee's four key themes: Defining the problem, studying blast injury mechanisms, studying blast-induced head injury, and mitigating blast injury.

HFM-207 Symposium Sessions

- Defining the Problem
- Complexity of Blast Injury
- Studying Blast Injury Mechanisms
- Studying Blast-Induced Head Injury
- Mitigating Blast Injuries: Materiel
- Mitigating Blast Injuries: Therapeutic

Summaries of the scientific sessions, presentation highlights, and overall recommendations are presented in this chapter. Technical papers and more information on this meeting can be found online (http://www.cso.nato.int/pibs/rdp.asp?RDP=RTO-MP-HFM-207).

Scientific Session Summaries

Defining the Problem

During this opening session, the presenters set the stage for the rest of the symposium by providing information that illuminated the scope of the problem. They covered the epidemiology of blast injury and mTBI in current operations, and the challenge of diagnosing and treating blast-induced mTBI. They also provided recent research findings on blast-related lung and ocular (eye) injuries.

In the Keynote presentation, COL John Alvarez, JTAPIC Program Manager, highlighted an ongoing case study where medical, operational, material, and intelligence data are being integrated to mitigate injury. The case involves an examination of combat injury data for warriors exposed to UBB injury and the use of these data to develop a blast ATD. Dr. Ralph DePalma of the VA subsequently provided a recent history of mTBI as related to blast. Dr. DePalma included estimates of the prevalence of mTBI from DoD and VA databases and discussed the challenges and opportunities related to the diagnosis, causes, and treatment of mTBI due to blast and concussion. The next three presentations covered blast-induced lung and ocular injuries. Dr. Iain Mackenzie of Queen Elizabeth Hospital Birmingham, England, focused on the etiology of blast lung injury in the military critical care population. CPT Matt Chauviere of the David Grant Medical Center highlighted case reports of US Soldiers who experienced hydrogen fluoride inhalation injury after their vehicle was hit with a rocket-propelled grenade, which damaged its fire suppression system and caused the release of the toxic hydrogen fluoride gas. Finally, CPT Brandon Phillips of the WRNMMC focused on ocular trauma following nonpenetrating blasts in Soldiers injured during OIF and OEF. CPT Phillips noted that, by documenting injury patterns, we may be able to provide more effective protection and management for these patients to decrease vision loss.

Complexity of Blast Injury

This session began with several presentations covering lessons learned from a variety of blast incidents, which demonstrated the wide variety of injuries that can result from blast exposure. The presenters also covered current strategies in the treatment of blast injuries to the extremities. Additionally, information was presented on computer modeling of blast injury as well as models that measure injury severity and predict therapeutic outcome.

Dr. Pierre Pasquier of Hôpital d'Instruction des Armées Percy, France, presented data from their retrospective survey of orthopedic injuries in 12 survivors of a 2002 bus bombing in Pakistan. Dr. Zurab Chkhaidze of Javakhishvili State University, Republic of Georgia, reviewed the types of blast-related injuries they observed in people injured during the August 2008 war in Georgia. Dr. Leo Klein of the University of Defence, Czech Republic, highlighted a case involving a combination of mechanical and burn injuries in a young man as a consequence of a disastrous explosion within the civilian rural industrial setting. Dr. Dan Bieler of the Central Hospital of the German Federal Armed Forces, Germany, subsequently provided an overview of the current strategies for treating blast injuries to the extremities. Col Jon Clasper of the Royal Centre for Defence Medicine, England, showed that the AIS is not an accurate predictor of long-term clinical outcome and that Foot and Ankle Severity Score would be a better quantitative measure of lower limb injury severity. Mr. Alan Hepper of the Defence Science and Technology Laboratory, England, concluded the session by addressing the computational modeling of the blast environment associated with the July 2005 London bombings, and the relation of modeling to clinical and engineering interpretations.

Studying Blast Injury Mechanisms

This session focused on the potential mechanisms of blast injury. A history of blast overpressure injury research was provided. The majority of the presenters focused on advances made and challenges associated with modeling, and simulating blast and blast injury to various parts of the body, including the lower extremity, spine, and auditory and vestibular systems.

A keynote presentation by Dr. James Stuhmiller of L-3 Communications/Jaycor focused on a history of blast overpressure injury research from the point of view of the driving objectives, tests performed, quantities measured, and conclusions drawn. Mr. David Ritzel of Dyn-FX Consulting Ltd., Canada, subsequently presented a brief review of blast physics and blast-wave simulation, highlighting an advanced blast simulator apparatus based on a novel shock tube designed to intrinsically replicate all the key features of blast-wave flow conditions. Mr. Charles Needham of Applied Research Associates reviewed some of the challenges associated with measuring and modeling the effects of blast on the whole body. Dr. Reuben Kraft of ARL described their research efforts to develop a hierarchical modeling approach for the lower extremities subjected to military UBBs. Mr. Bruce Amrein of ARL provided an overview of the Auditory Hazard Assessment Algorithm for Humans, which predicts and ameliorates the effect of very intense sounds on the ear. Dr. Bob Cheung of Defence Research and Development Canada highlighted their investigations into the effect of a primary blast wave on the functionality of the vestibular system using a computational fluid dynamics model. Dr. JiangYue Zhang of the JHU/APL elaborated on their development of a FEM for lumbar spine injury that is undergoing biomedical validation for the UBB loading environment (see presentation highlight). Dr. Lakiesha N. Williams of Mississippi State University concluded the session by describing the development and evaluation of a

Presentation Highlight

Dr. JiangYue Zhang—Johns Hopkins University Applied Physics Laboratory, USA
A High-Fidelity Model for Lumbar Spine Injury Investigation During Under Body Blast Loading

- Created a finite element human spine model based on properly scaled and generalized lumbar spine geometry obtained from the male subject in the Visible Human Project and evaluated its response under an idealized UBB acceleration loading.
- Found that von Mises stresses increased simultaneously at all levels from 0–11 ms during the compression stage until maximum compression was achieved (**Figure 5-1**). After 11 ms, stress at L1 continued to increase while all other levels experienced a degree of decompression. The continuously growing von Mises stress at L1 indicates higher probability of spine injury at this level.
- These initial findings may provide biomechanical insight to explain lumbar spine injuries observed during UBB events, such as wedge, burst, or chance fractures.

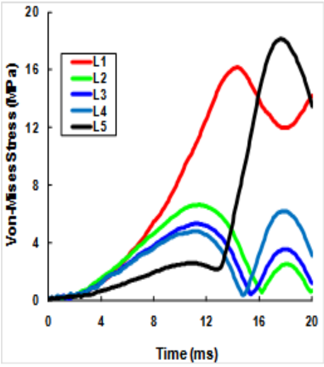


Figure 5-1. Von Mises stress in the anterior cortex of lumbar spine vertebrae

Presentation Highlight

Dr. Marten Risling—Karolinska Institutet, Sweden
Three Experimental Models for Evaluation of Three Different Mechanisms in Blast TBI

- The researchers are studying three models of blast exposure that generate TBIs with different distributions and outcomes (**Figure 5-2**):
  - The first model involves placing an anesthetized rat in a blast tube and then exposing the animal to controlled detonations of pentaerythritol tetranitrate (PETN) explosives that result in a pressure wave with a magnitude of 130–600 kilopascal (kPa). The animal is fixed with a metal net to avoid head acceleration forces.
  - The second model is a controlled penetration of a 2 mm thick needle, which is assumed to represent the focal impact of fragments.
  - In the third model, the animal is subjected to a high-speed sagittal rotation angular acceleration. This model is assumed to be relevant for the rapid acceleration movements that can occur after explosions.
- Experimental results using these models indicate that rotational acceleration may be a critical factor for diffuse axonal injury and other acute changes after blast TBI.

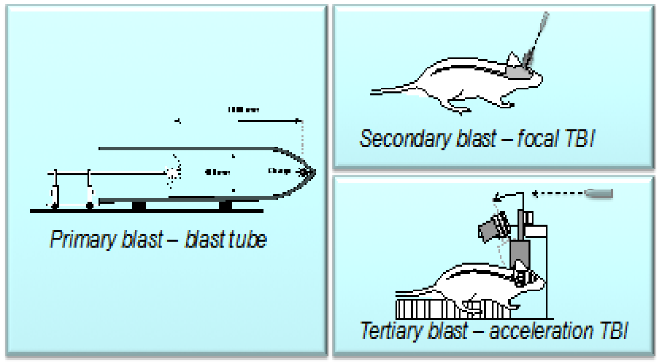


Figure 5-2. Schematic illustration of three models for primary, secondary, and tertiary blast. Acceleration movements have been limited in the blast tube in the first model. The focal injuries from impact have been represented by a model for focal penetration with a relatively high velocity. Effects of acceleration are studied by the use of a model for rotational injury.

lower extremity model at blast conditions using finite element analysis.

Studying Blast-Induced Head Injury

The focus of this session was on blast-induced injury to the head, and research spanned from animal modeling to human surrogates/modeling. The presenters covered experimental and computational models of TBI, cognitive and neurological performance impacts of blast injury, cellular and molecular effects of blast injury on neurons in the brain, and predictors of blast injury (e.g., effects of repeated blast exposures on brain biomarker levels).

A keynote presentation by Mr. Michael Leggieri, Director of the DoD Blast Injury Research PCO, provided an overview of computational modeling for non-impact, blast-induced mTBI, including information on DoD-related efforts in this area. Dr. Marten Risling of Karolinska Institutet, Sweden, subsequently described their three models of blast injury (primary, secondary, and tertiary) in the rat (see presentation highlight). Dr. Mikulas Chavko of the Naval Medical Research Center (NMRC) highlighted their studies on the impact of pressure waves on the rat brain following exposure to blast from a variety of orientations. Dr. Yushan Wang of Defence Research and Development Canada covered their research on the blast-induced degeneration of neurons in the rat brain. Dr. Joe Tsien of Georgia Health Sciences University highlighted their investigations of the impact of mild blast exposures on memory and behaviors using combined behavioral and large-scale neural recording techniques. Dr. Jurandir Dalle Lucca of the USAISR characterized the complement system and adaptive immune-inflammatory responses in a rat model of blast-induced neurotrauma. Dr. Peethambaran Arun of the WRAIR provided information on alterations in brain proteins related to hearing in their mouse model of repeated blast exposures.

The session continued with Dr. Gary Fiskum of the University of Maryland School of Medicine covering their work focused on testing for the specific effects of blast-induced hyperacceleration on the rat brain. Dr. Thomas Sawyer of Defence Research and Development Canada then reviewed the three-dimensional brain cell culture system they developed to study cellular injury resulting from exposure to single pulse shock waves. Dr. David Moore of Tulane University Medical Center highlighted their work in the development of interspecies scaling laws based on parameters such as body mass and brain volume in relation to energy deposition in central nervous system tissue due to stress-strain deformation secondary to blast wave propagation. Dr. Cynthia Bir of Wayne State University (WSU) covered their studies on the biomechanical responses of the post-mortem human subject during simulated blast wave interaction using a specially designed shock tube. Dr. Gary Kamimori of WRAIR presented data on their Breacher studies that were focused on quantifying the effects of repeated exposure to low-level blast on brain biomarkers, cognitive performance, and symptom reporting during a 2-week explosive entry training course. Lastly, Dr. Paul Rigby of L-3 Communications/Jaycor reviewed their work on the development of a transfer function that calculates the motion the head experiences when supplied with motion data from helmet mounted sensors.

Mitigating Blast Injuries: Materiel

This session covered the materiel development work associated with the mitigation of blast injuries. The presenters highlighted models and methods for assessing protective systems. They also covered experiments and models of blast insult to the head and brain (including the use of helmet protection), new materiel approaches for blast mitigation, and issues in the surgical and therapeutic care of blast-related injuries.

A keynote presentation by Dr. Vivian McAlister of the University of Western Ontario, Canada, focused on the role of surgical care in building resilience in Service members to blast attacks. Dr. Jean-Philippe Dionne of Allen Vanguard Corporation, Canada, presented their findings involving manikins wearing EOD PPE facing explosives located near walls, corners and corridors (see presentation highlight). Dr. Lisa MacFadden of L-3 Communications/Jaycor covered their work focused on evaluating the use of shock tube testing to screen armor system

Presentation Highlight

Dr. Jean-Philippe Dionne—Allen Vanguard Corporation, Canada

Increased Blast Injury Potential in the Vicinity of Reflecting Surfaces and Vehicle Borne Improvised Explosive Devices

- **The researchers completed numerical simulations of blast exposure for explosives located near walls, corners, and corridors (Figure 5-3).**
- **They then conducted experiments to confirm the simulation results (Figure 5-3, left panel)**
- **Their data confirmed the previous findings of Martec Ltd. (Halifax, Canada) showing that pressure profiles were significantly affected by the presence of these obstacles, resulting in higher blast impulse, and even in higher peak pressure in some cases.**
- **They determined that there exists an "optimal standoff" from the explosive charge where blast parameters are minimized, due to a balance between the blast exponential decay with distance, and increased blast threat from reflecting surfaces.**
- **These findings emphasize the need for bomb disposal technicians to avoid close proximity to walls and other obstacles, both around the explosive device itself, and surrounding the operator, to minimize the potential for overpressure injuries.**

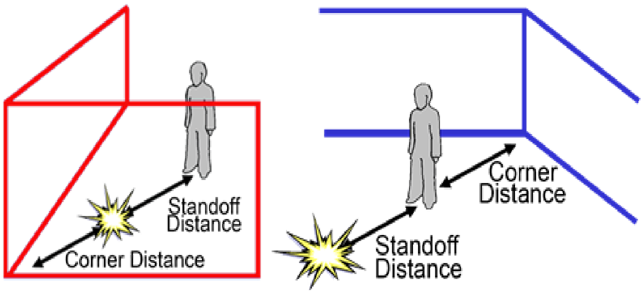


Figure 5-3. *Left:* Configuration for the first series of numerical simulations where the explosive is located between an individual and the reflecting surfaces. *Right:* Configuration for the second series of numerical simulations where the individual is located between the explosive and the reflecting surfaces.

candidates before moving to more extensive field testing. Mr. John Fitek of the US Army Natick Soldier Research, Development and Engineering Center focused on their work in developing a simple model of a plate and foam armor system to show the potential benefits and limitations of this concept for protection against primary blast lung injury.

The session continued with Dr. Liying Zhang of WSU highlighting their research focused on investigating how combat helmets influence the blast-induced mechanical loads in the human brain. Dr. Andrzej Przekwas of CFD Research Corporation then presented their data on the development of a comprehensive integrated experimental and computational framework to investigate blast wave brain biomechanics that will support design efforts to improve helmet protection under blast exposure. Dr. Roshdy Barsoum of the ONR presented their research showing that the incorporation of polymers with current helmet materials (Kevlar® or Dyneema®) can offer increased protection against blast, shockwave, and fragments with very low increase in helmet weight. Lastly, Dr. Mark Walker of Case Western Reserve University highlighted their findings confirming that disequilibrium in veterans with a history of mTBI is associated with decreased postural stability, particularly under more challenging conditions.

Mitigating Blast Injuries: Therapeutic

The final session focused on therapeutic regimens associated with the mitigation of blast injuries. The presenters covered a variety of animal models that are being developed to support new therapeutic approaches for blast-related injury. They also highlighted research involving the use of ultrasound to assess blast-related injuries, the development of a heuristic model of iron handling during blast trauma resuscitation, and recent efforts at managing blast injury in the field.

Dr. Stanislav Svetlov of Banyan Biomarkers presented data from their studies focused on comparing the effects of body/head exposure to a moderate primary overpressure with brain injury produced by a severe blast accompanied by strong head acceleration. Dr. Stergios Stergiopoulos of Defence Research and Development Canada covered the use of ultrasound pulses at different frequencies to track the dispersion properties of intracranial tissues that may have been altered due to traumatic or other neurological brain injury. Dr. Chaim Pick of the Sackler School of Medicine, Israel, highlighted their blast injury

Presentation Highlight

Dr. Chaim Pick—Sackler School of Medicine, Israel
Dr. Nigel Greig—National Institute on Aging, NIH
A Combat Zone-Like Mouse Model of Blast Brain Injury: Possible Translational Study to the Clinic

- The researchers have developed a blast injury model for mice that resembles the conditions in the battlefield or at a terror-attack site, and can be used to test therapies.
- Thirty days after blast exposure, the mice exhibited significantly decreased performance on both cognitive and behavioral tests at both 4 and 7 meters distance from the blast. Administration of the neuroprotective peptide Ex-4 reversed the cognitive damage of mTBI at this time point, as determined by a Y-maze test (**Figure 5-4**).
- Correlative Magnetic Resonance Imaging studies showed white matter and BBB changes 30 days post-blast.

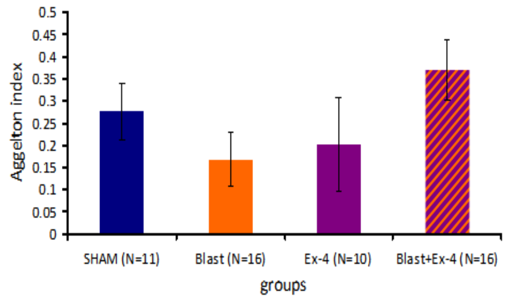


Figure 5-4. Results of the Y-maze test (ability to navigate in a novel arena). Performance of mice was evaluated 30 days post-trauma and preference index (Aggelton index) was calculated. Values are mean ± standard error of the mean.

model for mice, which has been designed to mimic the conditions in the battlefield or at a terror-attack site and can be used to test drugs (see presentation highlight). Dr. James Atkins of WRAIR covered the results of their studies on the mechanisms of iron-induced inflammation in the lung following blast exposure and discussed resuscitation strategies that may decrease the risk of developing acute respiratory distress syndrome. Lastly, Dr. Bryan Garber of the Canadian Forces Health Services described the Canadian Forces' approach to the management of blast-related mTBI in a military operational setting.

Overall Recommendations

The Technical Evaluation Report for the meeting presented the following two meeting recommendations.

1. Establish a recurring forum to promote technical exchange and collaboration on blast injury and its mitigation.[1] A biennial workshop on medicine and protection topics was suggested.
2. Develop a Technical Activity Proposal for activities related to a "toxicology of blast injury" focus area. This technical activity would address critical problem areas such as:
   - Relevancy and commonality of animal models
   - Common dose-response methods; route of exposure methods
   - Computational models (blast, physiology, biochemical, toxicological, etc.)
   - Dose regimens to human medical endpoints (surgical trauma to mTBI spectrum)
   - Methods for translational research leading to medical products and/or physical protection products

HFM-234 Technical Activity: Environmental Toxicology of Blast Exposures: Injury Metrics, Modeling, Methods, and Standards

The discussions at the HFM-207 Symposium revealed the need for a systematic approach to understanding blast injuries much like the well-established approach used to solve classical toxicology problems where the etiology of the

[1] Available online (http://www.cso.nato.int/pubs/rdp.asp?RDP=RTO-MP-HFM-207).

injury requires an understanding of the dose, mechanism of delivery of the dose, and dose-response endpoints. Also recognized was the pressing need for a multidisciplinary approach to addressing nonpenetrating blast injuries to the brain that result in a host of symptoms with vague etiology. Based on these needs, a Technical Activity was proposed for the toxicology of blast injury focus area. The NATO HFM-234 Technical Activity ("Environmental Toxicology of Blast Exposures: Injury Metrics, Modeling, Methods, and Standards") was subsequently approved, and the PCO Director was selected as the chair.

Fourteen members representing the nations of Canada, Estonia, France, Germany, the Netherlands, Norway, Sweden, UK, and the United States have been appointed to the HFM-234 Technical Team. The HFM-234 Technical Team will address a wide range of topics, including physics-based modeling of animals and man in relevant blast environments, blast exposure monitoring methods and metrics, and standardized protocols for blast injury research. Planning is underway for a July 2013 kick-off meeting at the NATO Science & Technology Organization, Collaboration Support Office in Paris.

The primary objectives of HFM-234 are to:

- Build an evidence-based outline for NATO standards for blast injury analysis
- Advance the state-of-practice in computational modeling of blast injury in relevant operational environments
- Explore standardized animal models, including blast exposure methodologies such as shock tubes, and toxicology research protocols that could be adopted by research and technology programs across NATO

Table 5-1 lists some the anticipated topics to be explored by HFM-234 technical activity. Final topics selected will be based on the interest and needs of the participating nations. HFM-234 is anticipated to be a 3-year effort that would establish a framework for a new interdisciplinary research area and culminate in a technical report with recommendations for advancing knowledge on blast injury in military personnel.

Table 5-1. Projected Topics for HFM-234 Technical Activity

Topics to Be Addressed
Toxicology methods relevant to understanding blast exposure effects
Physics-based modeling of animals and man in relevant blast environments
Physiological modeling of animals and man in blast environments
Standardized protocols for blast injury research
Medical surveillance data required to monitor acute and chronic effects of blast exposure
Medical screening methods and metrics
Blast exposure monitoring methods and metrics

Future Vision

The toxicological approach represents a new paradigm for the study of blast injury. The symposium and new NATO technical activity represent the first steps. Anticipated are additional technical exchanges as well as the coordination of research programs across the participating nations through the HFM Panel and other venues. Ultimately, this international collaboration is anticipated to advance the science, medicine, and mitigation technologies for blast injury.

Information and graphics for the Presentation Highlights provided courtesy of the authors and the NATO/STO/HFM Panel, and published in RTO-MP-HFM-207, October 2011.

Chapter 6

State-of-the-Science Meeting Series

The Blast Injury Research PCO established a State-of-the-Science Meeting Series in 2009 to assist in identifying knowledge gaps pertaining to key blast injury issues. These are narrowly focused meetings that help determine what is known and what is unknown about a particular blast injury topic. These meetings are designed to bring together top researchers, worldwide, from academia, DoD, other government organizations, and industry to share their expertise in helping focus future research investments that address these gaps.

The Blast Injury Research PCO intends to hold at least one meeting per year that critically assesses the state-of-the-science and provides vital evidence needed to prevent, mitigate, and treat blast-related injuries. Meeting topics are selected based on input from representatives of the CoEs and Joint Technology Coordinating Groups 5, 6, and 8 (MOM, CCC, and CRM, respectively).

Since its inception, three State-of-the-Science meetings have been hosted, and a fourth meeting is being planned for FY14. Highlights of these meetings are presented in the following paragraphs, and meeting summaries can be found on the DoD Blast Injury Program website at https://blastinjuryresearch.amedd.army.mil.

Upcoming: Limb Salvage and Rehabilitation (2QFY14)

With advances in battlefield medicine, more troops than ever are surviving with complex limb injuries. In an analysis covering the years 2000-2011, over 2,000 Service members suffered a major amputation (at least a hand or foot) of which approximately two-thirds were deployment-related.[1] Hundreds have suffered the amputation of multiple limbs.

Anecdotal evidence and initial results from the Military Extremity Trauma Amputation/Limb Salvage study revealed military lower limb amputees appear to have better functional outcomes than limb-salvage patients—in large part due to the intense integration of focused rehabilitation and state-of-the art prostheses.[2] However, recent advances in treatment to salvage limbs, via improved surgical techniques, more intensive rehabilitation regimens, and new technologies such as exoskeletal devices, now offer injured troops significantly more options than just amputation of the injured limb.

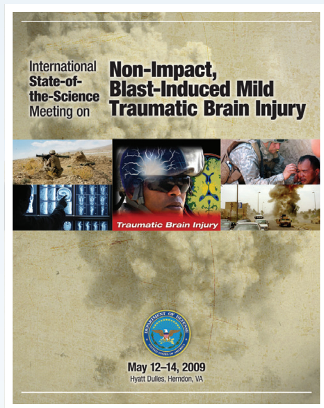
The DoD Blast Injury Research PCO, in cooperation with the VA, the Traumatic Extremity Injury and Amputation Center of Excellence, and the Center for the Intrepid, plans to host an International State-of-the-Science Meeting on Limb Salvage at Fort Detrick, Maryland in January 2014.

The objectives of this State-of-the-Science Meeting are to:

- Define Limb Salvage and identify/characterize the types of injuries that require limb salvage.
- Identify existing technologies and interventions that are most commonly used in limb salvage.
- Identify emerging technologies and interventions in limb salvage.
- Identify what can be done in the near term to improve the outcome and quality of life of Service members with limb injuries.

Approximately 100 SMEs from the DoD, other federal agencies, academia, industry, and the international community will be invited to participate in this meeting.

Previously Reported State-of-the-Science Meetings



Non-Impact, Blast-Induced Mild Traumatic Brain Injury, May 2009

Non-impact blast exposures occur when warfighters are close enough to an explosion to experience the high pressures created by the blast itself but far enough away to avoid penetrating injuries caused by fragments and blunt impact injuries caused by debris or by whole-body translation. The existence and mechanism of a non-impact, blast-induced mTBI remain a key knowledge gap.

Meeting Purpose

To critically examine research focused on the relationship between blast exposure and non-impact, blast-induced mTBI and to review proposed injury mechanisms.

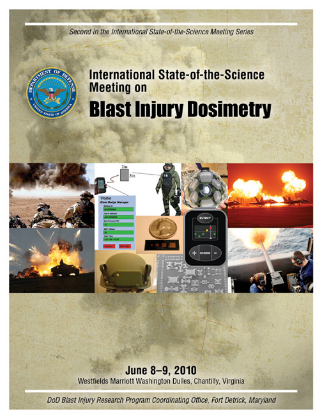
Recommendations

- Standardize research methods to facilitate research synthesis of comparable studies.
- Encourage detailed documentation of experimental and modeling work.
- Establish a data repository or atlas of studies for researchers to compare across models.

[1] Amputations of Upper and Lower Extremities, Active and Reserve Components, US Armed Forces, 2000-2011. *Mil Surv Month Rep*. 19(6) 2012: 2–6. Available at: http://www.afhsc.mil/viewMSMR?file=2012/v19_n06.pdf. Accessed Aug 26, 2013

[2] Doukas WC, Hayda RA, Frisch HM et al. The Military Extremity Trauma Amputation/Limb Salvage (METALS) study: outcomes of amputation versus limb salvage following major lower-extremity trauma. *J Bone Joint Surg Am*. 95(2) 2013: 138–45. doi: 10.2106/ JBJS.K.00734. Abstract at: http://www.ncbi.nlm.nih.gov/pubmed/23324961

- Encourage dissemination of findings in peer-reviewed literature.
- Support the recommendation to adopt common data elements on brain injury and psychological health.
- Develop a simple, far-forward evaluation platform (including balance, hearing, smell, and oculometrics) that can be implemented immediately after a blast event.
- Encourage research interactions between clinicians, engineers, and other disciplines.
- Emphasize the importance of the inclusion of proper control groups and protective equipment in experimental design.
- Create specialized Integrated Product Teams to periodically review emerging findings and make recommendations for research and clinical practice.



Blast Injury Dosimetry, June 2010

Warfighters are routinely exposed to blast-related insults in training and in combat. These insults range from occupational exposures associated with the use of weapon systems to potentially lethal exposures from explosive enemy weapons in combat. Examples of the types of potentially injurious blast insults they encounter include blunt impact, blast overpressure, impulse noise, and inhaled toxic gases. Through blast injury dosimetry, the DoD is seeking a way to objectively record and document these blast-related exposures and to correlate the exposures with acute injuries or chronic health effects.

Meeting Purpose

To identify and prioritize the blast injuries of concern that should be the focus of the DoD's blast dosimeter development efforts; determine whether blast dosimeters exist that can be fielded either now or within the next 2 years; and identify and prioritize the research gaps that exist in the development of blast dosimeters in the areas of both blast-related human effects modeling and sensor development.

Recommendations

- Establish a site at which sensors and testing methods (e.g., shock tubes and blast loads) from new and historic studies are evaluated to enable standardization of methods and measurements across studies.
- Field sensors or dosimeters only when there is a clear connection between data being collected and a specific injury.
- Ensure fielded dosimeters are as seamless as possible to the wearer by evaluating and minimizing the physical, logistics, and administrative impacts on the warfighter prior to fielding.
- Proceed with the Gen II helmet-mounted sensors and a concussion screening tool that uses well-known, well-documented concussion criteria.
- Establish a task force composed of sensor/dosimeter experts, engineers, modelers, mathematicians, and medical experts to review, interpret, and integrate existing historical datasets.
- Determine the upper and lower limits of blast energy or exposure that cause survivable injury for the injuries of concern so that sensors can be calibrated to detect within that range.
- Collect as much sensor data as possible from warfighters exposed to blasts and then decide what areas of research are most worthy of development.
- Expand the Breacher studies to investigate changes in the olfactory response pre- and post-exposure to repeated blasts.
- Conduct an extensive literature review to determine what has been done with regard to biomedical research on human effects models that correlate blast-related exposures with resulting injuries.

Blast-Related Tinnitus, November 2011

Tinnitus is defined as noise or ringing in one or both ears when no external sound is present. It can be a chronic, debilitating condition. Tinnitus most often results from either acoustic trauma or head and neck injury, which are prevalent injuries in current conflicts.

Meeting Purpose

To assess current knowledge regarding the cause, diagnosis, and treatment of tinnitus and to identify research gaps for further investigation. To foster collaboration among researchers and inform DoD research investment strategies.

Recommendations

Fundamental Knowledge Gaps:

- Determine the operational readiness impacts of tinnitus in the military.
- Enhance and utilize the Defense Occupational Environmental and Health Readiness System and other medical databases/registries to standardize and obtain data needed for the conduct of research studies. It is anticipated that policy and regulation issues would need to be addressed.
- Conduct a large-scale longitudinal study of blast-exposed and non-blast-exposed military personnel and veterans to gain insight on tinnitus onset factors and tinnitus progression.
- Determine if there are key markers for predicting an individual's susceptibility for developing tinnitus both before and following injury.
- Evaluate the relationships, if any, between tinnitus and other cognitive/psychological disorders.
- Continue to elucidate the mechanisms and contributing factors associated with tinnitus onset and progression to chronic tinnitus.
- Enhance existing and develop additional animal and experimental models/apparatuses to support the study of tinnitus, including blast and TBI, tinnitus distress measures, and blast shock tube exposure.

Applied Research and Technology Development:

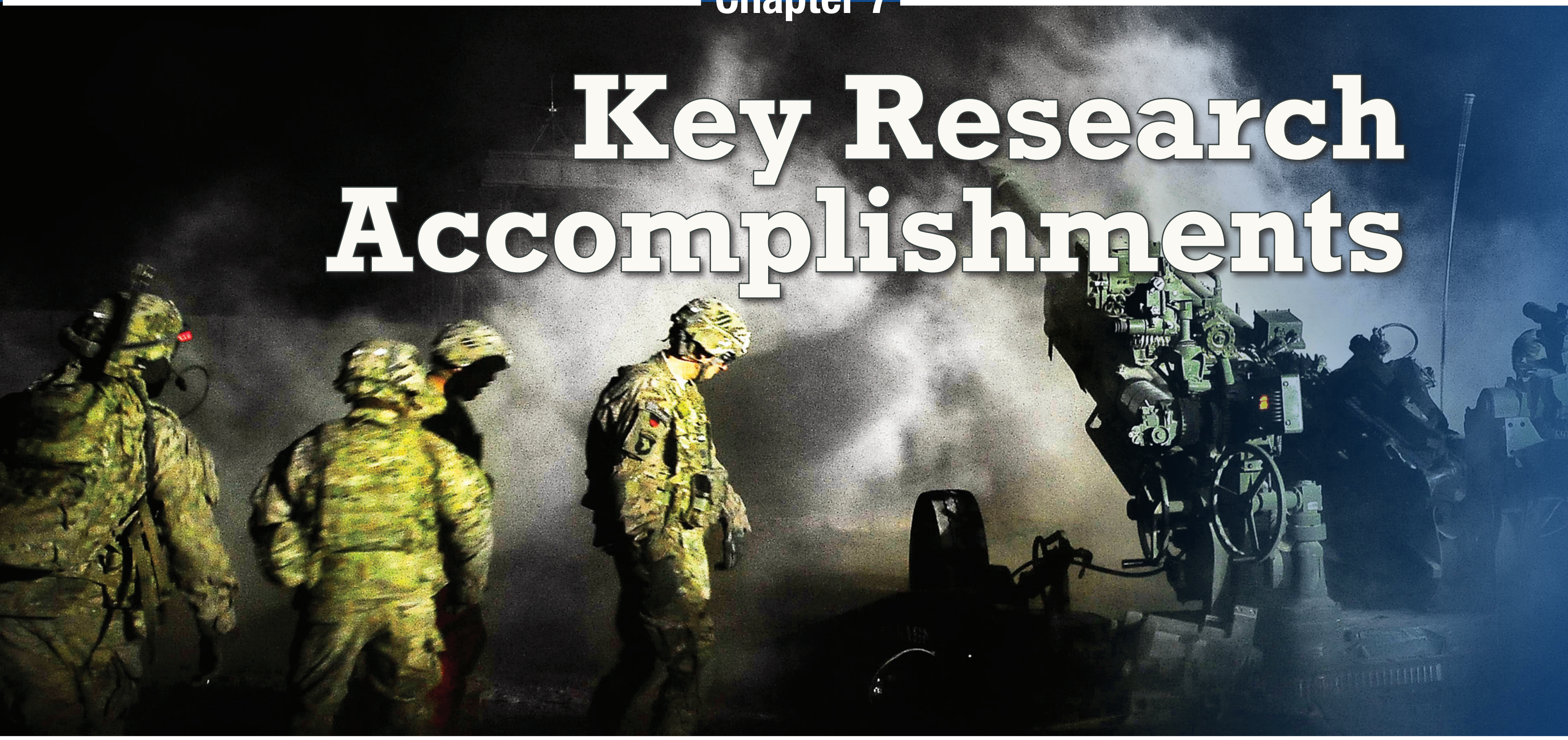
- Identify candidate pharmacologic strategies for early interventions that could prevent the cascade of damage to the cochlea and brain from leading to hearing loss and tinnitus.
- Develop improved and new imaging techniques to identify functional and structural changes that could be used to diagnose and characterize tinnitus.
- Develop improved tools and measures to assess tinnitus loudness, changes in tinnitus, and an individual's reaction to tinnitus.
- Develop tools for the objective diagnosis and characterization of tinnitus.

Clinical Research:

- Develop standard protocols and measures for conducting tinnitus-related clinical studies.
- Characterize the performance of existing technologies and modalities, alone and in combination, to diagnose and characterize tinnitus and possible subtypes.
- Conduct well-designed human studies of existing and novel therapies for preventing and treating hearing loss and tinnitus. This would include new uses for existing drugs; nutritional-and pharmaceutical-based strategies; and acoustic, electrical, and other stimulation technologies.

Chapter 7

Key Research Accomplishments



The Blast Injury Research PCO was established to coordinate the large number of relevant efforts that contribute solutions to the injury problems associated with blast threats. The Army, Navy, Air Force, and other DoD organizations conduct blast injury research. Many other federal agencies, as well as academia and industry, also play key roles in solving blast injury problems. A sampling of FY12 accomplishments is reported in this chapter. These accomplishments highlight the diversity of efforts and organizations that are committed to providing Soldiers, Sailors, Airmen, and Marines with the very best blast injury prevention, mitigation, and treatment solutions.

From Research to Fielded Products

Mitigating the Effects of Blast Waves on the Face with Maxillofacial Protection

Researchers at the University of Nebraska at Lincoln, with support from PEO Soldier, have demonstrated that the addition of a maxillofacial system (mandible and visor) to a combat helmet not only provides increased ballistic and blunt impact protection to the face but also mitigates blast waves. The mass added by the maxillofacial system—and its design—mitigate the effect of a blast wave to the head by disrupting its propagation and reducing the resulting pressure that is imparted to the head. PM SPE

prepared and received approval for a Material Change to the ACH requirement to procure maxillofacial systems and conduct additional testing. A total of 150 maxillofacial systems were procured in FY12 for this effort. Testing included ballistic and non-ballistic (low velocity blunt impact protection) as well as a user evaluation. Based on the results, the PM SPE obtained a Safety Confirmation and Capabilities and Limitations Report from the Army Evaluation Center. This documentation allowed for the remaining 100 maxillofacial systems to be provided to a unit to conduct training within CONUS and to utilize when the unit deployed outside CONUS. Feedback gathered from the unit will be utilized to refine the maxillofacial system and influence future requirements for the next generation of head protection—the Integrated Head Protection System (a component of the Soldier Protection System).

Improving the Bottle Bracket Design for the Stryker Mortar Carrier Vehicle Double-V-Hull (MCVV)

With funding from the PEO Stryker Brigade Combat Team, engineers from ARL's SLAD discovered a vulnerability of the Stryker MCVV's height management system (HMS) during live-fire testing. During underbody blast testing, a bracket designed to secure one of the nitrogen bottles for the HMS failed. The failure of this bracket during a UBB could cause crew injury due to the pressurized nitrogen bottle becoming a secondary projectile inside the rear crew compartment. During the damage assessment of the live-fire event, ARL/SLAD determined how and why the bottle bracket failed. Engineers from ARL/SLAD recommended a design change to the bottle bracket to ensure the HMS nitrogen bottle would remain secure. The design change was accepted and implemented on the MCVV, and follow-up testing demonstrated the security of the bottle bracket.

Predicting Injury with a Hazard Assessment Algorithm

Algorithms that can predict the likelihood of injury are critical to the Test and Evaluation and Health Hazard Assessment communities, and to weapons and material developers to prevent or reduce the risk of injury in training, operational, and combat environments. The Blast Overpressure Health Hazard Assessment tool, INJURY, which was designed and validated by L3/Jaycor Inc. and sponsored by the MOMRP, was adopted by US Army Public Health Command's Health Hazard Assessment program in FY12. With this tool, the Public Health Command can make hazard assessments for lung injury secondary to exposure to blast overpressure.

Assessing Optical Radiation Hazards to the Eyes and Skin

The US Army Public Health Command's Nonionizing Radiation Program (NRP) has developed a measurement technique to assess hazards to the eyes and skin from the optical radiation emitted by explosive devices (e.g., injuries resulting in visual impairment or burns to the skin). Inexpensive passive detectors, designed and used for more than 20 years, can evaluate hazards to the skin and eyes without the use of electronics, which are susceptible to acoustic and electromagnetic interference. The NRP devised a technique for making reliable radiometric measurements of optical radiation sources, including exploding devices, which limit the number of parameters that must be specifically measured. The results of this technique have been compared to traditional spectroradiometric measurements made in the NRP laboratory on a variety of continuous wave sources, and have agreed within a reasonable error. Notably, the NRP researchers have used the technique to assess optical radiation hazards from the M84E1 nonlethal grenade.

Recording Automotive Usage and Ballistic Data with a Black Box System

Researchers at ATC have developed and fielded a Black Box to install on military vehicles in an effort to better understand ballistic and automotive demands placed on vehicles operating in theater. The Black Box system contains a data recorder, derived from ATC's micro-Advanced Distributed Modular Acquisition System, and a customizable suite of sensors. The fielded Black Box solution includes a set of sensors that records a variety of automotive operations, as well as ballistic and rollover incidents, for detailed analysis. The ballistic data collected in theater are correlated with a library of ATC live-fire test events to identify the severity of the ballistic events in theater. Once a correlation is made, the Hybrid III anthropometric manikin data collected from a similar live-fire test event is compared to actual injuries reported from the event in theater to identify how accurately crew injuries were predicted during testing. For rollover incidents, automotive data are analyzed to reconstruct the rollover event to assess how the vehicle was being used at the time of the incident, and to aid in root cause investigations of the rollover. ATC's analysis also assists the PM in determining if specific vehicle upgrades are required. All automotive usage and ballistic data are compared to developmental and operational testing to determine if test operations adequately reflect how warfighters used the vehicles in theater.

Providing an Improved Assessment Tool for Measuring and Evaluating Impulse Noise

The US Army Public Health Command's Army Hearing Program (AHP) participates in the DoD Working Group charged with updating MIL-STD 1474D, DoD Design Criteria Standard—Noise Limits. MIL-STD 1474D is outdated and precludes Army acceptance of more powerful weaponry due to overly conservative impulse noise exposure limits. The AHP spearheaded a project to develop and implement a methodology to compensate for some of the deficiencies in MIL-STD 1474D. This included the development of new, innovative, interim impulse noise Damage Risk Criteria to enable progress toward establishing an assessment tool to replace that in MIL-STD 1474D. AHP scientists developed and recommended consideration of a technique that takes advantage of Artificial Test Fixtures (manikins with built-in noise sensors) fitted with Army-approved hearing protection to measure actual exposure levels to weapon noise. The AHP collaborated with the medical research community to focus research efforts on both short- and long-term tools for applying this new methodology. The AHP's Noise Control Engineer prepared and instituted both web-based and face-to-face programs to train industrial hygienists on the proper techniques for measuring and evaluating impulse noise.

Developing a Noninvasive Metabolic Sensor for Trauma Care

Researchers at Reflectance Medical, Inc. (RMI) were funded by the Combat Casualty Care Research Program (CCCRP) to develop the CareGuide Oximeter, a noninvasive metabolic sensor for trauma care that can provide an early warning of hemorrhage as well as diagnose sepsis. They have converted the prototype device to a robust, lightweight, easy-to-use product. The device is placed over a muscle on an arm or leg and allows the continuous, noninvasive measurements of muscle oxygen saturation and acidosis. It provides real-time feedback on the efficacy of fluid resuscitation. The researchers recently interfaced the reusable CareGuide sensor and single-patient sleeve with the Sotera ViSi mobile vital sign monitor. RMI has received

US Food and Drug Administration (FDA) 510(k) clearance for their device.

Reducing Blast-Related Ocular Trauma with an Eye Shield

The Vision Center of Excellence, working in close cooperation with the Committee on Tactical Combat Casualty Care (TCCC) and the Defense Medical Materiel Program Office (DMMPO), spearheaded the effort to include a protective eye shield (often referred to as a Fox shield) in the new Individual and Joint First Aid Kits (IFAK and JFAK) and to document its use on the 2013 edition of the TCCC card under review for approval for the official DoD-Form designation. The use of eye shields in cases of ocular trauma, including trauma sustained as a result of blast, is critical in mitigating an eye injury, thereby preventing associated vision loss or loss of an eye. Unlike with other parts of the body, no pressure should be applied to an injured eye; the rigid eye shield is designed to prevent bandage pressure that may induce secondary eye injuries. The DMMPO anticipates approval of a final JFAK that will include the eye shield in FY14 and the Vision Center of Excellence will continue to work with Service leadership to include the eye shield in IFAKs. The increased use and knowledge of the protective eye shield in theater will directly lead to a reduction in secondary eye injuries and enable improved outcomes for Service members who suffer visual system trauma.

Treating Combat Wounds with a Biologically Active Advanced Antimicrobial Human Skin Substitute

Stratatech Corporation has developed a human skin substitute for use in burn and trauma patients. With previous DoD AFIRM funding, researchers demonstrated that their human skin substitute performed as well as an autograft in effectiveness and safety. The FDA awarded Stratatech's human skin substitute orphan drug status in 2012. With Military Infectious Diseases Research Program (MIDRP) funding, Stratatech is developing a genetically enhanced human skin substitute that has sustained expression of cathelicidin—a naturally occurring, human-produced defense peptide with broad-spectrum antimicrobial properties that demonstrates effectiveness against multidrug-resistant bacteria and fungi. Initial preclinical studies have demonstrated effective antibacterial activity against multidrug-resistant Acinetobacter baumannii, one of the most common pathogens associated with combat wounds. More preclinical studies are underway with an Investigational New Drug submission proposed for 4QFY14. The availability of this product will contribute significantly to the prevention of antimicrobial infections in burn and trauma patients requiring skin grafts.

Restoring Amputee Balance, Locomotory Metabolism, and Speed with a Powered Leg Prosthesis

Researchers at the Massachusetts Institute of Technology (MIT) Media Lab, with funding from the TATRC, have developed the first power-driven prosthetic foot. A soleus-like actuator powers ankle movements that can actively push off the ground, replacing calf muscle function. The researchers demonstrated the ability of the prosthesis to adapt to a variety of walking speeds and reduce the metabolic energy cost of walking compared to traditional passive-elastic prostheses. This research led to the first commercially available powered prosthetic foot—the iWalk BiOM Ankle System—which provides active power generation (push off) to the user. The iWalk BiOM Ankle System is now being used by amputees from the active military, veteran, and civilian populations.

Injury Prevention – Injury Mechanisms

Preliminary Study with Emphasis on Lower Extremity Fractures in UBB Conditions

In collaboration with the injury biomechanics researchers at US Army Aeromedical Research Laboratory (USAARL) and funded by the Defense Medical Research and Development Program, researchers from the University of Virginia (UVA) Center for Applied Biomechanics are studying mechanisms of lower-extremity injuries resulting from UBB events, as well as developing a lower-extremity injury criterion that can be used to assess the safety of blast-resistant vehicles. Scientists at UVA have developed a unique intrusion sled system capable of reproducing blast-level accelerations in the laboratory. Using this sled system, instrumented test specimens are exposed to blast-level loading rates. The instrumentation measures forces and accelerations experienced by vehicle occupants during an under-vehicle blast event. These sensor data will be used to construct and validate a lower-extremity injury risk function for blast-rate floor intrusions. The researchers have developed hind foot dose injury mechanisms and criteria for UBB loads, and completed Post-Mortem Human Subject (PMHS) and Hybrid III match-pairing testing. This information will be used for biomechanics testing or manikin development.

Identifying Pathophysiological Damage to Ocular Tissues in Blast-Exposed Rats

With funding from the MOMRP, researchers at the USAISR, in collaboration with the NMRC, have found that the induction of mTBI in a rat following a moderate level of blast overpressure can also induce injury of the rat's ocular pathway. This is the first study to identify apoptosis (a cell death process initiated in response to stress, physical, or biochemical damage) in ocular tissues following exposure to sublethal blast pressure. The researchers identified the ocular tissues of the visual system that are most sensitive to blast exposure, specifically the optic nerve and cells in the ganglion and inner nuclear layers of the retina. The damaging effects of blast overpressure were observed in tissues from the side exposed to the blast as well as the contralateral side. These data will allow for the development of improved diagnostic tools and therapeutic interventions for warfighters who have been injured by blast exposure.

The Preventing Violent Explosive Neurologic Trauma (PREVENT) Program

PREVENT has illuminated the causes of blast-induced TBI, an injury that while previously described in the warfighter population, has been referred to as a potential "hidden epidemic" in the current conflict. PREVENT used a variety of modeling techniques based on in-theater conditions to assess potential TBI caused by blast in the absence of penetrating injury or concussion. DARPA has worked to create a model that can be directly correlated to the epidemiology and etiology of injury seen in returning warfighters, and has attempted to determine the physical and physiological underpinnings and causes of this injury. Raw data was collected from in-theater blast gauges, along with medical and event reports to form a comprehensive analysis. As part of the mitigation and treatment strategy, candidate therapeutics were tested for their capacity to alleviate inflammation from both acute and chronic injury.

Comparing Blast-Related and Non-Blast-Related mTBI in Service Members

With funding from the DCoE, researchers from the San Antonio Military Medical Center

performed a retrospective review of OEF/OIF Service members who presented for evaluation of suspected mTBI and underwent neurocognitive screening evaluations. A diagnosis of mTBI was made by semistructured clinical interviews. Sixty subjects were included in the final sample: 32 with blast mTBI and 28 with non-blast mTBI. Results indicate that there were no differences between the blast-related and non-blast-related mTBI groups on age, time since injury, combat stress symptoms, or headache. Analysis of variance showed no significant between-group differences on any of the neurocognitive performance domains. Although speculation remains that the effects of primary blast exposure are unique, the results of this study are consistent with prior research, suggesting that blast-related mTBI does not differ from other mechanisms of injury with respect to cognitive sequelae in the post-acute phase. The researchers at Defense and Veterans Brain Injury Center (DVBIC) also conducted a study comparing neuropsychological outcomes from blast-related versus non-blast-related mTBI of 56 US Service members who had sustained mTBIs while serving in theater during OEF/OIF. Participants were divided into two groups based on mechanism of injury: (1) non-blast related, and (2) blast plus secondary blunt trauma. The researchers' study measures included 14 clinical scales from the Personality Assessment Inventory and 12 common neurocognitive measures. Overall, the researchers found no differences between the two groups on all measures. This study suggests that blast exposure plus secondary blunt trauma does not result in worse cognitive or psychological recovery than blunt trauma alone.

A Valve-Based Microfluidic Axon Injury Micro-Compression (AIM) Platform

White matter tracts in the brain, which contain the axonal processes of neurons, can be damaged by blast exposure. Researchers at ATC, in collaboration with researchers at the JHU Whiting School of Engineering, developed a novel valve-based microfluidic AIM platform to enable focal and graded compression of microscale segments on single central nervous system axons. This platform allows, for the first time, the observation of axon deformation prior to, during, and immediately after focal mechanical injury. Using the AIM platform, the researchers have been able to obtain pressure-level thresholds for injury responses of continued growth, degeneration, and regrowth. Data generated in this study will allow scientists to obtain a clearer picture of the effects of blast on individual axons in the brain.

Elucidating the Relationship Between Blast mTBI and Postconcussive Syndrome (PCS)

Blasts have caused a greater percentage of injuries in Iraq and Afghanistan than in any other large-scale conflict. Researchers at the NHRC continue to explore the associations between in-theater injuries, particularly blast, and brain injury. With funding from the NMRC, the NHRC researchers assembled unique point-of-injury information available through the EMED and identified 491 male Service members who were diagnosed with mTBI and associated loss of consciousness. The researchers examined the association between blast- and non-blast-related mechanism of injury and a diagnosis of PCS. The results showed that headache, nausea and vomiting, and hearing deficits were more common in blast mTBIs, while memory problems were more common in non-blast mTBIs. A diagnosis of PCS was more than three times as likely in blast mTBIs compared with non-blast mTBIs, suggesting that mechanism of mTBI injury is a strong predictor of patient outcome. The results of this study have assisted military medical providers to better target interventions, enhancing CCC.

Studying the Effects of Repeated Low-Level Blasts in a Rodent Model

With funding from the Center for Neuroscience and Regenerative Medicine, researchers at the Uniformed Services University of the Health Sciences (USUHS) exposed rats to repeated mild blasts. They found that neuronal cell loss and inflammatory responses are the major pathologies following repeated mild blast exposure. They also demonstrated that repeated stress associated with transportation, etc., can be a major contributing factor to the observed pathologies. The researchers found that exposure to repeated mild blasts at "low frequency" results in a significant decrease in arterial oxygen saturation. The cumulative effect of multiple blasts at this “low frequency” is limited. Decreased arterial oxygen saturation can be one of the first signs of the primary pathologies that trigger downstream abnormalities. At a higher frequency of exposures, the cumulative effect is substantial, resulting in more robust downstream changes. Overall, these data underscore the potential for repeated mild blasts to cause brain-related damage in our Service members.

Finding Alterations in Genes Related to Auditory Function After Repeated Blast Exposure

Auditory dysfunction is one of the most common disabilities encountered among Soldiers returning from recent wars. Blast exposure can affect the peripheral auditory system as well as brain regions involved in central auditory signal processing. With funding from the CCCRP, researchers at the WRAIR are studying the expression of proteins and genes involved in central auditory signal processing in mice six hours after repeated blast exposures in a shock tube. Their preliminary data showed that the expression of the deafness-related genes otoferlin and otoancorin was significantly changed in the hippocampus after blast exposures. Differential expression of cadherin and protocadherin genes, which are involved in hearing impairment, was observed in the hippocampus, cerebellum, frontal cortex, and midbrain after repeated blasts. A series of calcium-signaling genes known to be involved in auditory signal processing was also found to be significantly altered after repeated blast exposures. The hippocampus and midbrain showed significant increase in the gene expression of hearing loss-related antioxidant enzymes. Histopathology of the auditory cortex showed more significant injury in the inner layer compared to the outer layer. In summary, mice exposed to repeated blasts showed injury to the auditory cortex and significant alterations in multiple genes in the brain known to be involved in age- or noise-induced hearing impairment.

Exploring Strategies to Improve Outcome After Repeated Mild Blast Exposures

Investigators at USUHS are conducting studies to determine the cellular, molecular, and behavioral abnormalities associated with multiple mild blast exposures, the relationship between observed pathology and the number and frequency of blast exposures, and the effect of “rest/recovery” on behavioral, cellular, and molecular outcomes. In one rodent model study, the researchers compared rodents exposed to a combination of one to three stressor variables (i.e., transportation, anesthesia, and blast sounds) to rodents exposed to these same variables plus mild blast overpressure. They analyzed sera and select brain regions for protein markers and cellular changes following blast exposure. Their findings demonstrated that experimental conditions, particularly exposure to blast sounds, can increase anxiety and trigger specific behavioral and molecular changes without injury. In a second study, rats were exposed to either single or multiple (administered over five consecutive days) mild blasts. The rats’ behavior was assessed at Day 1 and Day 16 after injury. Histological and protein analyses of brains and plasma were performed at early (2 hours) and late (22 days) time points. The results showed that repeated exposures to mild blast overpressure trigger early hippocampal cell death as well as neuronal, glial, and vascular damage that likely contribute to significant, albeit transient, increases in depression- and anxiety-related behaviors. In addition, the results revealed that frequency, or the elapsed time between exposures, is a critical factor in determining the severity of "cumulative" effect after multiple mild blast exposures.

Characterizing Blast-Induced Injuries of Deployed US Service Members

With funding from the NMRC, researchers at the NHRC conducted a descriptive analysis of 4,623 combat-blast episodes in Iraq between March 2004 and December 2007. The most frequent single injury type was mTBI. Other frequent injuries were open wounds of the lower extremity and open wounds of the face, including tympanic membrane rupture. The body regions most often injured were the extremities, followed by head and neck and torso. The majority of the blast episodes resulted in more than one injury, and the injuries varied across nearly every body region and injury type. In addition to confirming mTBI as the predominant injury from blast, these results highlight the risk of injuries to the extremities as well as the complex nature of blast injuries. Understanding the types and patterns of injuries due to blasts is assisting in the design of improved PPE and informing clinicians who are caring for the injured personnel.

Characterizing the Effects of Primary Blast Waves on the Visual System

Exposure to blast shock waves is a leading cause of vision loss in US military personnel. Blindness is a long-term disability that has a profound impact on the warfighter's quality of life. Researchers at the WRAIR, with support from the Vision Research Program, have begun studies to (1) characterize the nature of blast wave injuries to the retina and brain visual processing centers and (2) explore novel drug therapeutics to halt the progression of any resulting neuronal cell degeneration. Using a rat model of whole-body exposure to blast overpressure in a shock tube, the researchers are assessing visual function by electroretinogram recordings, visual discrimination behavior testing, and eye and brain histopathology. Results to date show that exposure to moderate-pressure blast waves leads to marked visual system dysfunction that is associated with retina and brain neuronal apoptosis (cell death), (i.e., retina photoreceptor cell and brain axonal tract degeneration).

Developing an Ultrasound Device to Simulate Blast-Related Brain Injury

Researchers at USUHS have developed a high-intensity focused ultrasound (HIFU) apparatus that can simulate a primary blast wave. The wave mimics the time course of an open-field, blast overpressure wave ranging from 1–10 milliseconds in duration. The apparatus disrupts the integrity of the BBB after a single HIFU exposure. The BBB normally protects the central nervous system from harmful contact with immune system messengers (and other products in the blood) that can induce an immune reaction in the brain, inflammation, and possible downstream long-term effects on brain function. The research team built the HIFU apparatus to simulate primary blast-induced brain injury so they could assess neuroimmune responses resulting from the disruption of the BBB. Recent improvements in the device have included a handheld component that uses a "cone" to place the HIFU transducer directly on the scalp of the mouse, thereby making it easier to properly align the transducer and deliver a more intense HIFU wave. Researchers at the USUHS have employed the improved device in more than 1,500 rodent experiments aimed at better understanding the biological and behavioral responses to HIFU-induced brain injury.

Characterizing the Molecular Mechanisms During the Subacute and Chronic Periods After TBI

Distinct molecular and cellular changes occur following TBI. The CCCRP-funded researchers at WRAIR are characterizing the molecular changes that occur during the subacute (7–28 days post-injury) and chronic (> 1-month post-injury) time periods following (1) penetrating ballistic-like brain injury (PBBI) or (2) projectile concussive impact injury. Researchers are conducting systematic analyses of protein and micro Ribonucleic Acid (miRNA) in tissues and biofluids to evaluate peripheral inflammatory cell infiltration, resident glial activation, oxidative damage, and miRNA biomarkers. The researchers found that inflammation, as indicated by the presence of glial fibrillary acidic protein in serum, is a biomarker in rodents for mild and moderate TBI. In addition, microarrays indicated altered miRNA regulation 24 hours after PBBI, silver staining revealed that axonal damage increases 7 days after PBBI, and subacute (10-day) treatment with the neuroprotective agent Simvastatin improved learning and attention after PBBI.

Conducting Deployment Injury Surveillance

The US Army Public Health Command's Injury Prevention Program systematically collects, analyzes, interprets, and disseminates injury data for the deployed and nondeployed Army populations. Annual surveillance reports describe injuries within the context of all medical encounters (illness- and injury-related) to assess the overall impact of injuries in the Army. These reports also describe the injury rates, trends, types, anatomic distributions, and causes, for battle and non-battle injuries. Injuries that result from the effects of blast, such as TBI, urogenital injuries, and amputations, are included in these annual reports. A unique objective of this deployment injury surveillance is to identify and classify the causes of non-battle injury that may be preventable. In FY12, the Injury Prevention Program completed a technical report describing the incidence of TBI that resulted in death, in-theater hospitalization, or air evacuation from the theater. The report notes that 80% of the battle-related TBIs were caused by the effects of blast from IEDs.

Injury Prevention – Injury Models

Investigation of Whole Body Response to Vertical Blast Loading Environments

There are significant gaps in understanding how the complex loading of UBB events causes injuries. In recognition of these gaps, USAARL, in collaboration with ARL, created an experimental capability to induce differential and controlled loading conditions to a test specimen similar to that experienced by a vehicle occupant subject to a mine blast event. The Accelerative Loading Fixture was created to facilitate the investigation of mechanisms and phenomenon as they relate to the response of seated occupants of military vehicles subjected to buried blast loading. In this effort, USAARL provided subject matter expertise on the medical research portion of the project and assistance in the requirements for fixture design. The USAARL research team included academic researchers from the Virginia Polytechnic and State University (VT) and Ohio State University. ARL led the research on blast loading and its implication in the design of the test apparatus. The USAARL and ARL teams met in March 2012 to set goals for this experimental capability and to develop design options. The teams then developed design goals for the experimental fixture. Over the next 6 months, the ARL team led the fixture design, fabrication, and construction culminating in several developmental prove-out test shots. The first full-scale experiment on the Accelerative Loading Fixture was completed in October 2012. Numerous tests have subsequently been completed with both mechanical human surrogates and PMHS.

Capturing the Human Response to UBB Loading Using Finite Element Modeling

A UBB can cause severe injuries to the lower extremities, particularly the lower leg and foot as well as the lumbar spine, leading to permanent disability and loss of life. To mitigate these types of injuries, ARL used computational biomechanics as a research tool to predict human injury and thus to enable better and more informed protection design. In collaboration with the Walter Reed Army Medical Center and others, utilizing computing resources such as those provided by ARL's DoD Supercomputing Resource Center, ARL researchers have built high-resolution FEM of anthropomorphic lower extremities and the lumbar spine capable of simulating bone fracture. Simulations have shown a link between the acceleration of a deforming floor plate and the amount of bone damage sustained in the foot and ankle region in a UBB event.

Building Mathematical Models to Study Blast Loading Rates on Manikin Materials

Researchers at ARL's WMRD are building models to mathematically represent the response of existing and novel manikin materials at different loading rates, including blast loading rates. They are specifically investigating the rate-dependent behavior of neck rubber from the Hybrid III, an ATD used by the automotive industry, over multiple strain rates using different types of loading. Mathematical models have been obtained representing the response of the neck rubber from the Hybrid III manikin for use in computer codes, which will aid in the future development of ATDs.

Seated-Soldier Project

The Tank Automotive Research, Development and Engineering Center (TARDEC) worked with the University of Michigan Transportation Research Institute to conduct the Seated-Soldier Project. Over a 4-month period, a total of 300 Soldiers at three different military bases were measured and scanned in various equipment and clothing. The purpose of the study was to determine how increased gear encumbrance worn by Soldiers affects their seating positions, and to create tools that will allow military ground vehicle seat developers to properly design seats for 90% of the Soldier population. Tools to be developed include occupant accommodation models for driver and crew positions, JACK manikins, Pro-E manikins, and possibly other tools that may not have yet been realized. Data will be used for developing ATDs and for updating MIL-STD-1472, Human Engineering, the DoD's standard for general human engineering design criteria, principles, and practices to be applied in the design of systems, equipment, and facilities.

Standardized Test-Rig for PMHS Studies

Project 4.2 of the Jumpstart Program addresses the injury response following simulated UBB conditions using PMHS and existing manikins. The PMHS and Hybrid III ATD seated in a blast buck testing apparatus will be exposed to acceleration generated by explosives that are placed underneath the buck. Since tests near or slightly above the threshold for injury hold the most value for this project, most charge levels that are being investigated are categorized as mild. The primary product from this effort will be data on kinematics (transducer and video) and injury characteristics of PMHS. In June 2012, VT, ARL's WMRD, and USAARL finalized the design of a standard test rig to be used for the studies and reviewed a seat design. Design specifications were released for the test rig and the final seat design will be recommended for standardization.

Developing Microscale Models to Obtain a Biomechanical Understanding of mTBI

With funding from MOMRP, L-3/Jaycor completed an extensive literature review of damage mechanisms for mTBI at the tissue and axonal levels. This review generated guidance for the development of axonal and micro-mechanical models aimed at understanding how mechanical perturbation may result in alterations to neuronal signaling without obvious structural damage (a hallmark of mTBI). To obtain the mechanical perturbations for microscale modeling, the researchers used existing data sets and models developed to calculate the motion of the head due to blast or blunt trauma. This macroscopic motion translates to strains, strain rates, and stresses in brain tissue, and this is being modeled with a biofidelic finite element head model. The researchers assembled an initial structure that ties external loading to macroscale brain motion to microscale axonal response and to an estimate of axonal damage. The purpose of the initial effort was to demonstrate that a causal link could be built and that the end-to-end response was credible. From that effort, the researchers have identified specific areas in each link of the chain that must be researched, developed, and validated to provide the broad, biomechanical understanding of concussion needed by the military.

Modeling Blast Injury for the Treatment of Traumatic Vision Loss

With funding from TATRC, researchers at Vanderbilt University have developed the first animal model that examines the effect of blast injury on the eye. They are using this model to explore the types of cells that are affected by blast exposure and the cell death pathways involved. They characterized the effect of blast exposure on C57Bl/6 mice and DBA/2J mice. The C57Bl/6 mice exhibited a mild injury response while DBA/2J mice had a more robust injury response. These studies suggest there is a genetic component underlying the responses of military Service members to blast exposure, and this may explain why some Service members are more severely affected by the same blast. The researchers are also using this model as a platform to test potential therapeutic agents.

Investigating Blast Mitigation Through Computational Modeling of the Human Head

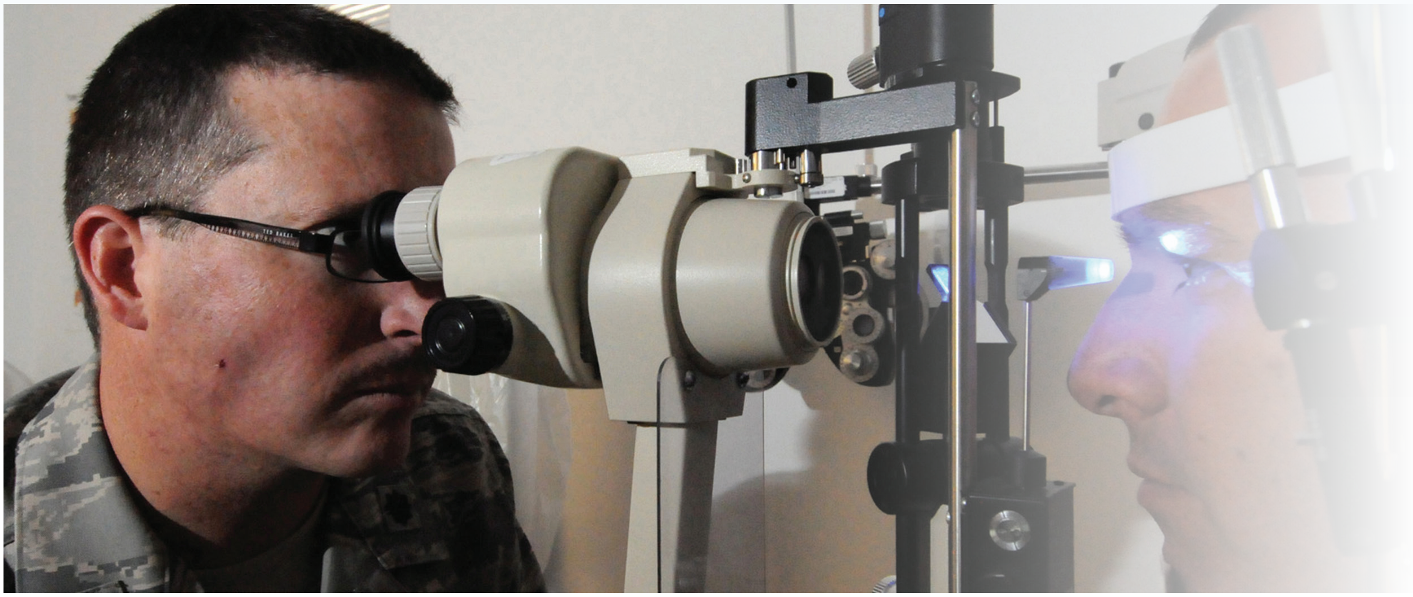
The Institute for Soldier Nanotechnologies at the MIT, collaborating with researchers from ARL's WMRD, the University of Washington Medical Center, and the Neuroscience Center at Massachusetts General Hospital, integrated new studies of cranial bone and neural cells with a high resolution, anatomically correct mathematical model of the human head to quantify the mechanical properties of highly anisotropic cranial bone at the tissue level and the injury response of primary brain cells in three-dimensional cultures to mechanical shock, and elucidate a fundamental understanding of the complex mechanisms that underlie blast-induced brain injury. The researchers then investigated the effect of the ACH and a conceptual face shield on the propagation of stress waves within brain tissue following blast exposure by extracting pressure histories at three points within the skull and cerebrum. They found that the helmet alone only slightly delayed and reduced the magnitude of pressure peaks, whereas the helmet–face shield combination had a much more pronounced mitigating effect. Data from these experiments were published in Proceedings of the National Academy of Sciences and are expected to contribute to the development of improved protective equipment, diagnostic tools, and treatments for blast-related injuries to the head.

Developing and Characterizing In Vivo Models of Blast-Related Spinal Column Injury

Researchers at USUHS are developing in vivo models to elucidate the effects of blast exposure on the spinal column. The goals of their study are to: (1) outline pathophysiological changes within the spinal column and the surrounding musculature following exposure to pure blast, (2) evaluate the effects of blast in different combat environments on musculoskeletal spinal trauma, and (3) perform a pilot characterization of the effects of blast on spinal injury in a large animal model. The researchers will replicate three major in-theater operational conditions: free field, blast attack on a Humvee, and urban warfare. These models will permit the systematic characterization of blast-induced pathologic changes within bone, disc, surrounding soft tissue, and blood and nerve supply. To date, the researchers have collected samples from 135 control and experimental animals exposed to explosive blast. The peak pressure of the blast exposures ranged from 16–22 psi and did not kill the animals. In addition to gene expression and histology, the researchers began to process blood to investigate protein biomarkers and coagulation. They found that animals exposed to blast overpressure demonstrated hypercoagulation through 10 days post-exposure. This finding has important clinical implications for the treatment of any individual exposed to blast, with or without additional injury. Notably, ARL is integrating the researchers' FEM lumbar model into smaller elements. They have completed the facets and are initiating the validation of the model. Upon validation, the researchers expect to be able to test multiple blast scenarios. Improving understanding of the post-blast orthopedic pathology will pave the way for developing early diagnostic and therapeutic strategies to improve the management of blast-related spinal injury and ultimately prevent and/or alleviate disability in our warriors.

Creating a Spatiotemporal Computational Model of Neurotrauma

Researchers at ARL's WMRD have developed a novel method of integrating brain injury biomechanics and graph theoretical analysis of neuronal connections, or connectomics, to create a computational model that captures the spatiotemporal characteristics of trauma. The method relates localized mechanical brain damage predicted from finite element simulations of the human head subjected to impact and blast with degradation in the structural neuronal network for a single individual. The FEM incorporates information from a magnetic resonance imaging technique that allows in vivo tracking of axonal fiber bundles in the white matter of the human brain. This physics-based approach to modeling neurotrauma will help scientists understand how the local mechanical



response of the brain in blast events leads to widespread effects on the structural network of the brain. ARL is currently seeking ways to validate the axonal damage predicted within the FEM using in vivo diffusion-weighted imaging techniques.

Developing a Computational Model of the Eye

With funding from TATRC, researchers at JHU developed a fluid structure interaction solver and a computational model of the human eye to examine the effects of facial features and tissue properties on blast pressure loading. They found that the nasal and brow ridges act as reflectors that focus pressure loading on the eyes. This also generates an asymmetric pressure loading on the eye that leads to gross distortion of the globe within the extra-ocular tissues. The deformation of the globe had little effect on the blast pressure loading on the eye. Understanding the evolution of the stress and strain fields from dynamic pressurization is needed to develop a stress analysis, which is ultimately required to determine the key mechanical properties of the tissues, understand injuries and develop more effective protection systems for the eyes.

Injury Prevention – Protective Equipment

Testing and Optimizing Urogenital PPE

The Natick Soldier Systems Center; UK Ministry of Defence, UK Defence Science and Technology Laboratory; Naval Research Laboratory; and PEO Soldier are collaborating to evaluate urogenital PPE. The researchers developed standard operational procedures for damage evaluation of PUG and POG blast tests. They documented blast effects early in the blast sequence on the PPE worn by the warfighter. Of note, the early shockwave was different in field blast tests than that demonstrated in the shock tube; it was much more complex with positive and negative components. The researchers found that the outer covering of the PPE was displaced by the primary pressure wave and destroyed very early in the blast sequence. Since the fire retardant clothing was damaged prior to the flash component of the blast, it did not afford burn protection. The researchers will repeat blast events during the upcoming year to see if product modifications are effective in retaining the protective panel in place longer.

Developing Polymers for Protection Against Blast and Blunt Exposure

The combination of lightweight polymers with high-strength Kevlar can provide increased protection against blast and ballistic threats. During the past 5 years, the ONR has supported research efforts on polymers (specifically, polyurea). Existing polymers, including polyurea, are being tested at the Naval Surface Warfare Center, Carderock Division (NSWCCD). Researchers at NSWCCD in cooperation with DuPont, Inc. (through a Cooperative Research and Development Agreement), are developing a helmet that protects the wearer from blast exposure without sacrificing ballistic capability. These helmets have been associated with significant reductions in pressure and impulse following blunt trauma exposure. Researchers at the MIT are analyzing the results using biofidelic computational models. Their preliminary findings are positive, indicating that the polymers may reduce the effects of blast on the brain.

Blast Eye Injury Criteria Development and Protection

With funding from the MOMRP, USAARL researchers used a shock tube to model the blast dynamics of eye trauma using custom head forms and sensors. They measured pressure readings at the cornea to assess gaps between protective eyewear lenses and the face to identify ocular injury mechanisms. Some of the eye protection schemes tested (including some on the Authorized Protective Eyewear List) failed to reduce the intensity of blast pressure waves reaching the cornea. The complex interaction of the pressure waves with the eyewear may cause waves with higher pressure to reach the eye, particularly in certain head orientations relative to the blast source. Pressure waves reaching the cornea with some eyewear exhibit a periodic waveform in time-pressure recordings. These oscillations may cause increased shearing stress to ocular tissue. Findings from this study could eventually lead to better designs in ballistic protective eyewear.

Blast Attenuating De-Coupled Vehicle Underbody Development for the Ground Fleet

The US Army TARDEC Ground Systems Survivability organization has developed unique de-coupled underbody integration concepts and underbody integration standards. Several underbody concepts have been designed, built, and evaluated against the more traditional, rigidly integrated underbody systems found on the currently fielded ground fleet. Testing has shown that the high accelerative forces experienced by the vehicle and crew during a blast may be reduced by effectively stretching out, or attenuating, the loads induced from IEDs. Results from these efforts will enable improved vehicle survivability and occupant protection and will culminate in a RDECOM demonstration program.

Improving Combat Helmet Design

Soldiers have been utilizing the ACH and its pad suspension system in combat since 2002. The ACH and its pad suspension system were designed to provide ballistic protection to the head as well as non-ballistic protection, such as low-velocity blunt impact. While the Army was aware that the helmet provided additional protection to the Soldier, that additional protection was not quantifiable. In FY12, researchers at UNL, with support from PM SPE, demonstrated that blast waves captured under the helmet were disrupted by the ACH suspension system pads in their approved configuration. The PM SPE continues to fund research exploring the correlation between material properties and dynamic impact response to develop an improved helmet suspension system capable of demonstrating increased non-ballistic and blast protection. Information gathered from this research has directly influenced future requirements for the next generation of head protection, the Integrated Head Protection System (a component of the Soldier Protection System).

Occupant-Centric (OC) Platform Technology-Enabled Capability Demonstration

The OC Platform Technology-Enabled Capability Demonstration integrates and synergizes OC foundational process and tools and interior/exterior OC technologies into an essential design process. The design process is subsequently validated and verified through M&S evaluation and LFT&E testing of three demonstrator platforms. The foundational processes, test tools, technologies, and OC design best practices ultimately will be consolidated into a comprehensive OC design standard for delivery in 2015–2016. The principal OC Platform success performance goal for the demonstrators is a 50% reduction in casualties (WIA/KIA) over the baselines established for the demonstrators. An important component and early activity of the program has been to identify and assess theater injury data from Iraq and Afghanistan (data and analysis provided by the JTAPIC Program), develop injury reference values through an extensive evaluation and review process, and establish an injury assessment reference value database. The program will evaluate the performance of the individual technologies, integrated components and subsystems, and standalone systems, all of which will be integrated into the demonstrators against injury assessment reference values as the principal metric for casualty reduction.

Developing an Energy-Absorbing, Blast-Mitigating OC Seat

Concurrent Technologies Corporation has teamed with the US Army's TARDEC to develop an energy-absorbing, blast-mitigating seat for 90% of the Soldier population, with increased load representation of PPE. Phase I of the contract focused on designing, developing, and testing the energy-absorbing feature of the next-generation OC seat. Phase II focused on full seat system final design, modeling, and simulation, as well as drop tower testing of the seat with the 5th, 50th, and 95th Hybrid III ATDs. Test results show that careful selection and tuning are vital to meet injury reduction criteria for the small female, and the mid-size and large males, for multiple impulse loads.

Acute Treatment – Diagnostics

Detecting TBI with an Automated Magnetoencephalography (MEG) Imaging Method

Researchers from the DVBIC, with funding from the DCoE and in collaboration with the Naval Medical Center San Diego, investigated the use of MEG low-frequency source imaging to support the clinical diagnosis of TBI. Forty-five subjects with mTBI were enrolled in the study (23 combat-related blasts and 22 non-blast causes). Seventeen of the blast-induced mTBI subjects had tertiary injuries resulting from the blast. Tertiary injuries involved a fall, hitting other objects (e.g., hitting parts of a vehicle when the vehicle was hit by an IED or other type of explosive), or being hit by other flying objects following the initial blast. Additionally, 10 moderate TBI subjects (non-blast) were enrolled. The researchers applied their automated MEG low-frequency source imaging method to all of the enrolled subjects. The results indicated that this method detected abnormalities at an overall rate of 87% for the mTBI group and 100% for the moderate TBI group. Among the mTBI subjects, the rate of abnormalities was 96% for the blast group and 77% for the non-blast group. The spatial characteristics of abnormal slow-wave generation in the mTBI blast group correlated significantly with those in non-blast mTBI. Among 96 cortical regions, the likelihood of abnormal slow-wave generation was less in blast-induced mTBI subjects than in the non-blast mTBI subjects, suggesting possible protective effects due to military helmets and armor.

Developing Diffusion Tensor Imaging (DTI) Phantoms to Enhance TBI Diagnosis

DTI, a subset of magnetic resonance imaging, can produce detailed structural maps of the brain. These maps can show axonal injury associated with mild or moderate TBI. Understanding the susceptibility of axons to shearing forces associated with TBI may reveal the physiological underpinnings of these injuries. This DTI technique could aid in the characterization of TBI, as well as comorbid PTSD. This technique also offers a platform to discover imaging biomarkers of TBI. With funding from TATRC, researchers at SA Photonics have developed a DTI phantom prototype capable of reproducible, basic magnetic resonance measurements in a magnetic field. They expect Phase II of this project to result in advanced prototyping, with the potential to improve the imaging of axonal fiber crossings. The researchers are currently refining the basic design for reproducibility and temperature dependence.

Developing a Biological Dosimeter of Blast Injury

Researchers at the WRAIR are exploring the utility of blood measurements of several plasma enzymes, including aspartate aminotransferase, alanine aminotransferase, lactate dehydrogenase, and creatine kinase, as biological dosimeters of blast exposure. With funding from the CCCRP, they are using a mouse model of single and repeated blast exposure in a shock tube to study the release of these enzymes from traumatized organs into the circulation. Their data show that activities of all of the enzymes in the plasma were significantly increased as early as 1 hour after blast exposure. Enzyme activity remained elevated for up to 6 hours in an overpressure dose-dependent manner, and returned close to normal levels at 24 hours post-blast. Brain injury alone most likely does not contribute to the systemic increase in enzymes, since head-only blast exposure with body protection showed no increase in the enzyme activities. The researchers concluded that overpressure-dependent transient release of tissue enzymes and elevation in the plasma after blast exposure suggests that enzyme activities in the blood could be used as a biological dosimeter to assess the severity of blast injury.

Rapid Diagnosis of Acute Brain Injury with the Real-Time EEG Monitoring System (R-TEEMS)

The R-TEEMS is an onsite electroencephalograph EEG system that is intended to rapidly detect, monitor, and automatically communicate in real-time the dynamic condition of brain function and dysfunction to onsite medics or other caregivers. The R-TEEMS monitors the dynamic state of the injured brain and detects key EEG patterns signifying progressive brain injury. The graphical user interface communicates these patterns and significance using easy symbology, severity trending, and alarms. The result is rapid detection of acute brain injury complications at earlier and more reversible stages, leading to more timely and accurate treatment. It is anticipated that the R-TEEMS will improve the timeliness of diagnosing secondary brain injury, and the appropriateness of corrective intervention, to enable immediate and accurate management decisions at all echelons of health care and evacuation within and outside the combat zone. Funded by TATRC and developed at Jordan NeuroScience, Inc., the R-TEEMS is in final clinical studies at Duke University Medical Center.

Developing a Diagnostic Marker of Blast-Induced Chronic Traumatic Encephalopathy (CTE)

CTE is a Tau protein-linked neurodegenerative disorder observed in athletes with multiple concussions. The clinical symptoms and neuropathological characteristics of CTE overlap with those observed in blast-exposed individuals. Prevention of Tau phosphorylation and facilitation of the dephosphorylation of phosphorylated Tau are critical in prevention of tauopathy and preservation and restoration of neuronal microtubule assembly. Tissue-nonspecific alkaline phosphatase (TNAP) serves this major role in the brain by dephosphorylating phosphorylated Tau. With funding from the CCCRP, researchers at WRAIR have shown that the activity and expression of TNAP in the rat brain significantly decreased after blast exposure. The decrease in TNAP activity/expression was associated with increased phosphorylation of Tau, revealing the potential role of TNAP in the development of tauopathy and CTE after blast exposure. This decrease was also associated with a decreased level of TNAP activity in the plasma, which indicates the potential use of TNAP activity/level in the plasma or cerebrospinal fluid as a diagnostic marker of blast-induced tauopathy/CTE.

Evaluating Central Auditory Processing Disorders in Blast-Exposed Service Members

In collaboration with the Hearing Center of Excellence and the National Center for Rehabilitative Auditory Research, researchers from the WRNMMC have made significant progress in the development of clinical assessment tools for evaluating central auditory processing disorders in military personnel who have been exposed to blast. Over the past 10 years, many military and VA audiologists have reported seeing a large number of blast-exposed patients who had audiometrically normal hearing, as measured by a pure-tone audiogram, but who

complained about difficulties understanding speech in noisy environments. In FY12, the researchers from WRNMMC published the results of a study showing that blast-exposed listeners performed substantially worse than non-blast-exposed controls on a battery of clinical central auditory processing tests. The researchers also completed data collection in a Defense Medical Research and Development Program-funded study that was focused on determining how well blast-exposed listeners could perform functional listening tasks (e.g., audio-visual speech perception and auditory localization). The results of this study have been used to develop a rapid screening test for blast-related central auditory processing disorders that requires less than 10 minutes to complete and appears to be more sensitive than any previously reported test. The new screening test has been adopted for use in the clinics at WRNMMC and the NICoE.

Identifying Biomarkers for Acute and Chronic TBI

Researchers at the University of Pittsburgh are focusing on identifying and evaluating biomarkers with prognostic value across the TBI spectrum. With funding from the TATRC, the researchers first transformed their data management process to a centralized relational database system and set up a comprehensive inventory and tracking system for biosamples. Their study focused on identifying markers of inflammation using cerebrospinal fluid and serum samples taken 1 week after severe TBI as well as serum samples derived from those with chronic TBI. The researchers also studied neurotrophin profiles after acute and chronic TBI as well as hormone levels after chronic TBI. They also conducted genotyping studies focused on hormone biomarkers relevant to cognition, posttraumatic epilepsy, and depression. The researchers at the University of Pittsburgh collaborated with researchers at Banyan Biomarkers, Inc. to identify new biomarkers relevant to chronic TBI and conduct pilot studies in clinical samples. The completed work has formulated the basis for the introduction and development of “Rehabilomics,” which involves (1) an emphasis on biomarker studies aimed at understanding the biochemical mechanisms of injury, comorbidity, and recovery; and (2) the assessment of biomarker profiles in relation to multimodal outcomes and susceptibility to complications relevant to rehabilitation.

Developing Smart Oxygen Monitors to Diagnose and Treat Cardiopulmonary Injuries

Cardiopulmonary injuries, such as from hemorrhage and lung injury, can be fatal if not rapidly recognized and treated. Diagnosing these potentially survivable injuries with noninvasive, near-term technologies is an area of intense investigation. Oxygen monitors with decision support software are needed to rapidly and accurately detect and treat deficits in oxygenation. To address this objective, researchers at the University of Texas Medical Branch (Galveston), funded by the CCCRP, have

developed a prototype system that monitors the fraction of inspired oxygen and automatically maintains arterial oxygen saturation. Further testing in mechanically ventilated injured animal models is planned.

Acute Treatment – Epidemiology

Identifying Transient Altered Consciousness Induced by Blast Exposure and Its Relation to PCS

Researchers from the DVBIC, in collaboration with the Hunter Holmes McGuire VA Medical Center Healthcare System, conducted a study to assess the value of recalled alteration of consciousness (AOC) symptoms collected via a questionnaire in evaluating individuals exposed to blast during a recent military deployment. With funding from the DCoE, investigators analyzed items that signified unconsciousness and/or posttraumatic amnesia for their frequency and distribution of positive versus negative responses, inter-item agreement, and relation to current neuropsychiatric symptoms including those consistent with PCS. A total of 87 active-duty Service members or Veterans who experienced acute effects from a blast within the past 2 years while deployed for OEF/OIF were enrolled. Results showed that 29 subjects responded positively to at least one of three AOC items: gap in memory, memory not continuous, or told by observer they had experienced a loss of consciousness. AOC items were associated with, but nondiscriminate of, current symptom distress on standardized measures of PCS, PTSD, depression, and pain. The investigators concluded that the positive association between a subject's questionnaire-based AOC item responses and current symptom complex measures suggest that mTBI has a role in the development of chronic neuropsychiatric symptoms after blast exposure.

Investigating Four Technologies to Assist in Detecting TBI in Service Members

Researchers at ARL Human Research and Engineering Directorate conducted a study focused on examining four technologies—a force plate, a brain acoustic monitor, voice analysis software, and the Automated Neuropsychological Assessment Metric 4 (ANAM4)—for their usefulness in assisting practitioners during screenings of Service members for a potential TBI diagnosis. The researchers were blinded to the head injury status of 88 active-duty and retired Service member volunteers (35 with a diagnosis of mild to moderate TBI; 53 who had never had TBI). Each volunteer was evaluated by a member of the TBI treatment team before completing an assessment with each of the technologies. Initial analyses have been completed, and results include the development of a clinical prediction rule, with two force plate variables and one ANAM4 mood scale variable, deemed helpful in predicting the presence of TBI. While these results are preliminary, they present important clues for future research efforts and offer additional information to assist with the detection of TBI.

Discovering and Validating Peripheral Biomarkers of TBI

Traumatic injury to the brain is a known risk factor for development of Parkinson's disease (PD) and several other neurodegenerative conditions. With funding from TATRC, researchers at Georgetown University are developing methodologies to examine markers extracted from the peripheral blood and correlating specific clusters of expressed molecules characteristic of deficits resulting from traumatic injury to the head as well as the clusters indicative of PD development and comorbid conditions associated

with PD. The researchers have identified specific markers that reliably separate individuals with PTSD from unaffected individuals. They have also been able to separate individuals at increased risk for development of minimal cognitive impairment from unaffected individuals in a retrospective biomarker study. The development of molecular fingerprints characteristic of the aftermath of traumatic injury to the head should provide a screening mechanism for the determination of the state and status of injured Service personnel. More importantly, the clusters should correlate with specific functional impairments and potentially indicate specific molecular pathway derangement specific to particular individuals, making individualized treatment and rehabilitation more likely. For PD, which is a potential risk for the long-term health of military Service personnel, additional findings suggest that clusters associated with initiation and progression of PD will be useful in identifying military personnel who have been exposed to PD risk factors during operations and identifying potential intervention strategies for prevention of performance and health impairments.

Assessing Health Outcomes Associated with Military Deployment

Researchers at the DVBIC, in collaboration with researchers from the James A. Haley Veterans' Hospital and Bay Pines VA Healthcare System, and with funding from the DCoE, have investigated the association between specific military deployment experiences and immediate and long-term physical and mental health effects, as well as the effects of multiple deployment-related TBIs on health outcomes.[1] Study participants were members of the Florida National Guard (1,443 who had deployed and 1,655 who did not deploy). The main outcome measures were the presence of current psychiatric diagnoses and health outcomes to include post-concussive and non-post-concussive symptoms. Using an online survey that was completed by participants approximately 32 months after deployment, researchers found that participants who had deployed had significantly poorer health outcomes than those who did not deploy. Deployment-related mTBI was associated with increased depression, anxiety, PTSD, and post-concussive symptoms, collectively and individually, when compared to those who had deployed but did not experience

[1] Vanderploeg RD, Belanger HG, Horner RD, et al. Health outcomes associated with military deployment: mild traumatic brain injury, blast, trauma, and combat associations in the Florida National Guard. *Arch Phys Med Rehabil* 93(11) 2012. doi: 10.1016/j.apmr.2012.05.024. Abstract at: http://www.ncbi.nlm.nih.gov/pubmed/22705240

an mTBI. Statistically significant increases in the frequency of depression, anxiety, PTSD, and post-concussive symptom complex were seen when comparing single and multiple TBIs. A pre-deployment TBI did not increase the likelihood of sustaining another TBI in a blast exposure. Associations between blast exposure and abdominal pain, pain during deep breathing, shortness of breath, hearing loss, and tinnitus suggested residual barotrauma. Combat exposures with and without physical injury were each associated not only with PTSD but also with numerous post-concussive and non-post-concussive symptoms. The experience of seeing others wounded or killed, or experiencing the death of a buddy or leader was associated with indigestion and headaches but not with depression, anxiety, or PTSD. The researchers concluded that complex relationships exist between multiple deployment-related factors and numerous overlapping and co-occurring current adverse physical and psychological health outcomes. Various deployment-related experiences increased the risk for post-deployment adverse mental and physical health outcomes, individually and in combination. These findings suggest that an integrated physical and mental health care approach would be beneficial to post-deployment care.

Project BLAST: The Balad/Bagram Longitudinal Assessment of the Symptoms of PTSD and Acute Stress Disorder (ASD)

The assessment tools often used to evaluate blast-injured patients for physical and psychological trauma in the deployed setting were not designed to take into account the possibility of comorbid PTSD/ASD and TBI, which is a shortcoming in this area of research. The Office of the Air Force Surgeon General is sponsoring Project BLAST, a retrospective and prospective analysis of the symptoms and symptom clusters in TBI and PTSD/ASD, in an attempt to disentangle these two prevalent injuries in OIF Veterans. Phase I will include a retrospective evaluation of the comprehensive TBI and PTSD/ASD clinical assessment data already collected on 682 brain-injured patients previously evaluated by the research team at the Air Force Theater Hospital at Joint Base Balad; an expert panel of military and civilian experts in TBI, PTSD/ASD, psychometrics, and biostatistics to analyze these data and attempt to distinguish between the symptoms and diagnoses of TBI and PTSD/ASD; and, development of a prospective TBI and PTSD/ASD assessment battery to be conducted after blast injuries sustained in Iraq (based on the results of the retrospective data review). Phases II and III of the study will address the prospective analyses. Objectives are to (1) test the prospective assessment battery developed during Phase I, (2) conduct follow-up evaluations on prospective study participants, and (3) test the predictive validity and clinical utility of the prospective assessment battery. The researchers will develop a recommended decision tree for diagnosing and treating patients.

Acute Treatment – Hemorrhage and Blood

Increasing Survival from Internal Hemorrhage Using a Hemostatic Foam

Uncontrolled internal hemorrhage is the leading cause of death for warfighters on the battlefield. The vast majority of these deaths is due to internal hemorrhage that cannot be visualized and treated in the field by compression or tourniquet before lifesaving transport to a medical treatment facility can occur. Currently, no method other than surgical intervention can effectively treat such intra-abdominal, noncompressible injuries. The Wound Stasis System program at the DARPA aims to develop a stasis material and delivery system, suitable for combat medic use at the point of injury, to stabilize the patient for medical transport. The Wound Stasis System could potentially effectively treat noncompressible hemorrhage, regardless of geometry or location within the abdominal cavity, without requiring direct visualization of the wound site by the medic. The researchers have developed a self-expanding, polyurethane-based polymer that has demonstrated statistically significant improvement in survival for a lethal swine liver model created in a closed abdominal cavity. Overall survival at 3 hours was 73% in the polymer group (animals receiving fluid resuscitation plus intraperitoneal injection of hemostatic foam) compared with 8% in the control group (animals receiving only fluid resuscitation). Median survival time was more than 150 minutes in the polymer group versus 23 minutes in the control group.

Developing Freeze-Dried Plasma (FDP) to Manage Hemorrhage on the Battlefield

Battlefield mortality due to hemorrhage may be reducible by up to 33% with new or improved measures for the management of hemorrhage. Fresh frozen plasma (FFP) is a blood product used in the current standard of care. Up to 40% of FFP supplied to the battlefield is wasted due to breaks in packaging during trans-shipment and outdating once thawed. Researchers funded by

the CCCRP are developing freeze dried plasma, a dehydrated form of FFP. The FDP is less temperature-sensitive and reconstitutes more quickly than FFP. It is anticipated that fielding of FDP will help reduce the waste associated with FFP and will augment FFP by allowing its use closer to the point of injury and earlier in the treatment regimen.

Acute Treatment – Wound Repair and Stabilization

Developing and Optimizing a Fieldable Training System for Medics

Researchers at ARL have developed the Vehicle Extrication Trainer (V-Xtract), a portable, rugged, reconfigurable, and reusable training system, to give medics and combat lifesavers experience with casualty extrication and medical care treatment following IED blasts. The V-Xtract uses Army Property Disposed vehicles as physical training mock-ups. The V-Xtract fills a training need with the development of core requirements based on the blast cues and realistic scenarios. It employs advanced, specialized M&S training tools and tracks trainee performance to provide

after-action review feedback. Iterative research, prototype development, experimentation, and testing are being conducted to complete the project and transition it to a Program of Record.

Reducing Corneal Scarring Following Burn and Blast Injuries

Burn, blast and other injuries to the eye caused by explosions during combat or terrorist attacks are devastating injuries that typically impair vision by excessive corneal scarring. With funding from TATRC, researchers at the University of Florida, Gainesville, tested and identified a triple combination of small interfering Ribonucleic Acids (siRNAs) that generated a true synergistic knockdown of the expression of the collagen and alpha smooth muscle actin (α-SMA) genes (by 97% and 94%, respectively) in rabbit corneal fibroblast cultures without compromising the viability of the rabbit corneal fibroblasts. They developed nanoparticle formulations containing this triple combination of siRNAs and showed, using ex vivo rabbit globes, that the nanoparticles effectively delivered the siRNAs to all layers of the rabbit cornea. The research team performed a pilot test of this formulation in vivo using the rabbit corneal excimer laser ablation model that simulates blast injuries. They achieved an effective knockdown of collagen and α-SMA gene expression in two of three rabbits. The results from this research pave the way toward the development of a multi-targeted approach for reducing not only corneal haze but also scarring in the entire body.

Acute Treatment – Wound Infection

Developing Clinical Practice Guidelines for Combat-Related Deep Soft Tissue Infections (DSTI)

The DoD/VA Trauma Infectious Disease Outcomes Study is funded by the MIDRP and led by the Infectious Disease Clinical Research Program, a worldwide network of DoD clinical and research centers that collaborate to investigate infectious disease challenges facing the military from the point of injury through echelon IV and V (Landstuhl Regional Medical Center, Germany and CONUS-based hospitals) treatment facilities. This research study involves multiple DoD and VA medical treatment facilities and is designed to produce evidence-based data for the development of Clinical Practice Guidelines for the prevention and management of DSTI associated with combat-related injuries. The Trauma Infectious Disease Outcomes Study researchers are investigating clinical outcomes from the current management of combat-related DSTI. At initial in-patient hospitalization, skin and soft tissue infections accounted for more than 40% of infections associated with combat-related injuries. Eighty-five percent of the skin and soft tissue infections were DSTI. In initial analyses, the researchers evaluated the number and rate of DSTI as well as initial antibiotic regimens. This information is currently under review to determine how to modify clinical practice to improve outcomes.

Development of Therapies to Prevent and Treat Wound Complications in Combat Casualties

Researchers at the USAISR have been funded by the CCCRP to evaluate the effects of bacterial biofilms on wound healing in vitro and in vivo. They are investigating the use of biofilm dispersal agents and adjunctive therapies for chronic infections to develop better wound irrigation guidelines and irrigants. Their approach consists of using in vivo animal models to screen and evaluate currently used and emerging therapies that can reduce complications such as fracture nonunions and wound dehiscence. Their priority is the development of acute therapies that can be used during the MEDEVAC chain. Incorporation of D-amino acids (D-AAs, a biofilm dispersal agent) into a bone graft prevents it from becoming contaminated by a clinical strain of bacteria that is a high biofilm producer. Results suggest that the local delivery of D-AAs reduces the biofilm and can enhance the activity of systemic antibiotics against bacteria within a biofilm. This will facilitate wound healing and reduce complications.

Developing Rapid Microbiological Diagnostics for the Prevention and Management of Wound Infection

With funding from the MIDRP, researchers at the Denver Health Medical Center and University of Colorado Medical School, in collaboration with the Denver VA Medical Center, Accer18 Technology, and other medical facilities, are developing a capability for rapid microbiological identification and drug resistance phenotyping with the use of novel, multiplexed digital microscopy. Conventional bacterial culturing can take days to identify bacterial species and drug-resistant phenotypes. This delay can lead to inappropriate and ineffective therapies for some patients given the observed increase in multidrug-resistant bacteria. Using advanced microscopy and bacterial culturing techniques, the researchers are developing the capability to identify bacteria and determine drug resistance profiles within six hours of receiving the specimen. Accer18 Technology has developed a prototype microscopy device that demonstrates the ability to detect real-time bacterial growth under various media conditions (with and without antibiotics). This early success indicates great potential for real-time microbiological diagnostics. It is anticipated that the ability to significantly increase effective treatment with the correct antibiotics earlier during infection will lead to improved outcomes in both infection and healing in cases of traumatic wounds.

Acute Treatment – TBI Treatment

Decreasing Blast-Related Cerebral Edema in a Mouse Model

Malignant cerebral edema (fluid accumulation in brain tissue) plays a major role in the pathophysiology that evolves after severe TBI. Added to this are the significant morbidity and mortality from cerebral edema associated with acute stroke, hypoxic ischemic coma, neurological cancers, and brain infection. Therapeutic strategies to prevent cerebral edema are limited and, if brain swelling persists, the risks of permanent brain damage or mortality are greatly exacerbated. Researchers from Trinity College Dublin, Ireland, and Duke University funded by the TATRC used an experimental mouse model to demonstrate that a temporary and size-selective modulation of the BBB allows enhanced movement of water from the brain to the blood and significantly impacts the amount of brain swelling. The researchers also showed cognitive improvement in mice with focal cerebral edema following administration of siRNA directed against claudin-5 (a protein found in the cell membrane). These observations may have profound consequences for early intervention in cases of TBI, or indeed any neurological condition where cerebral edema is the hallmark pathology. The researchers have recently initiated a preclinical safety and toxicology screen in nonhuman primates.

Using Hyperbaric Oxygen (HBO2) Therapy to Treat Chronic mTBI

With funding from United States Army Medical Materiel Development Activity and contributions from the US Navy and US Air Force (USAF), three Phase III studies on the use of HBO2 therapy for chronic mTBI have been completed, and a fourth confirmatory study is ongoing. These studies utilized different doses and deliveries of HBO2 at various pressures compared to different sham treatments to help determine whether HBO2 is beneficial in the treatment of chronic mTBI. The USAF study, a single-center, double-blind, randomized, sham-controlled, prospective trial conducted at the USAF School of Aerospace Medicine, examined the effects of HBO2 use on post-concussion symptoms in 50 military Service members with at least one combat-related mTBI. Overall, they found that HBO2 at a pressure of 2.4 atmospheres absolute had no effect on post-concussive symptoms after mTBI. The HBO2 Therapy for Persistent Post-Concussive Symptoms After mTBI study has been completed, and data analysis is ongoing. The US Navy/Richmond VA study has been completed, and data are being prepared for publication. The ongoing confirmatory study, Brain Injury and Mechanisms of Action of HBO2 for Persistent Post-Concussive Symptoms After mTBI, has an expected completion date in June 2014.

Developing a Nutrition-Based Treatment for Blast-Induced TBI (bTBI)

The large incidence of bTBI in combat casualties has prompted recognition of the need to establish the means to increase TBI resilience to hasten safe return-to-duty and minimize long-term and delayed TBI-related debilitations in returning Veterans. With funding from the CCCRP, investigators at WRAIR are using laboratory rats to establish whether an omega-3 polyunsaturated fatty acid (Ω-3 PUFA)-deficient diet (mimicking a contemporary Western diet) promotes blast-related TBI vulnerability and whether a concentrated Ω-3 PUFA emulsion given intravenously immediately following bTBI serves as an effective countermeasure to bTBI. The researchers have established that consumption of a high-fat diet deficient in Ω-3 PUFAs promotes an increased Ω-6/Ω-3 PUFA ratio resulting in a pro-inflammatory state following bTBI. The Ω-6/Ω-3 status is significantly reduced by a continuous intravenous infusion of the Ω-3-enriched emulsion over five days following bTBI and is accompanied by significantly improved clinical outcome as measured by neurobehavioral testing. These researchers concluded that the intravenous infusion of an Ω-3-enriched emulsion is an efficacious treatment for the management of bTBI in this rodent model and may represent a safe and effective therapy for bTBI in military Service members.

Aiding Recovery from Severe TBI with Caffeine

TATRC-funded researchers at the Legacy Research Institute in Portland, OR, are studying the influence of pre- and post-exposure to caffeine on survival and injury outcome after a TBI. They modeled severe TBI in adult male rats by subjecting the animals to a lateral fluid percussion injury (FPI). The animals received various combinations of acute or chronic caffeine treatment before and after the FPI. The researchers demonstrated that an acute dose-dependent bolus of caffeine, when given immediately after the injury, prevented lethal outcome. The researchers also showed that chronic caffeine consumption prior to the TBI did not influence the post-injury outcome. Thus, chronic caffeine use among military personnel can be considered safe. On the other hand, the investigators discovered that withdrawal of caffeine after the TBI (by default in the most severe cases, because Soldiers can no longer consume caffeine when unconscious or hospitalized) was associated with better outcome compared to groups in which chronic caffeine was re-instated after the FPI. They found that chronic caffeine treatment post-injury impaired motor recovery. The researchers anticipate that these findings will lead to additional studies that can ultimately be translated to create recommendations for the use of caffeine on the battlefield and beyond.

Developing Neuroprotection Strategies for Treating PBBI

The CCCRP has funded a partnership between the WRAIR and Operation Brain Trauma Therapy, a multicenter, preclinical drug screening and brain injury biomarker development consortium for TBI, to fully characterize and define the optimal treatment parameters of promising neuroprotective agents for treating PBBI. The researchers have begun to develop combination therapies by identifying the neuroprotection provided by individual drugs such as progesterone and simvastatin. They completed testing of erythropoietin and cyclosporine A in WRAIR's PBBI model. They also completed monotherapy dose-response profiles for simvastatin and cyclosporine A. The next phase of this project is designed to identify potential synergisms that are produced by the combined effects of the best neuroprotective drugs.

Improving Outcomes for Service Members with TBI

The State of Maryland Emergency Medical System and the R. Adams Cowley Shock Trauma Center are conducting research focused on improving outcomes in individuals with TBI utilizing human and animal models. With funding from TATRC, the research is being conducted in three sub-projects: cytokines, animal, and vital signs. The first 2 years focused on infrastructure development, development of a basic science protocol, development and institution of two human use protocols, staff acquisition, equipment purchase, and the implementation of a robust brain resuscitation registry to provide structure and linkage capabilities for data collection and outcome reporting. Year 3 accomplishments included the ongoing enrollment of subjects in the human use protocols focusing on the inflammatory process following TBI and the vital sign response to trauma, the development and implementation of two retrospective human use protocols, processing of specimens for the cytokines sub-project, and initiation of the basic science model including both small and large animal models of polytrauma. During the past 2 years, data collection and data analysis were completed for the cytokines and animal sub-projects, data analysis continued for the vital signs sub-project, and development of the final human use sub-project continued. The researchers found that early femur fracture fixation in TBI subjects correlates with significantly reduced hospital and length of stay in the intensive-care unit. They also determined that hyperoxemia (elevated levels of oxygen in the blood) within the first 24 hours of hospitalization increases mortality and worsens short-term functional outcomes in TBI subjects.

Reset – Regenerative Medicine

Developing a Vascularized Skin Construct Using Stem Cells from Debrided Burned Skin

Burns covering large surface areas of the body present a significant therapeutic challenge. Researchers at the USAISR, funded by the AFIRM, have isolated autologous stem cells from the adipose (fat) layer of surgically debrided burned skin, using a point-of-care stem cell isolation device. They found that, after these cells were placed in a collagen, fibrin-based hydrogel and exposed to the appropriate stimuli, they would differentiate into an epithelial layer, a vascularized dermal layer, and a hypodermal layer. The researchers completed an immunocytochemical analysis that showed a matrix- and time-dependent change in the expression of stromal, vascular, and epithelial markers. Overall, their results indicate that stem cells isolated from debrided skin can be used as a single autologous cell source to develop a vascularized skin construct without the need for culture expansion or the addition of growth factors. This technique is therefore a promising alternative approach for cutaneous skin coverage after extensive burn injuries.

Developing Novel Stent Grafts for Vascular Trauma and Replacement

Researchers at the Cleveland Clinic, funded by the AFIRM, are developing a tissue-lined, bioabsorbable, nitinol-based, fracture-resistant stent graft to address vascular trauma experienced in theater. They evaluated the stent graft in a canine iliac artery injury model. All animal implants were successful after 30 days. The researchers have also developed a Gen II, user-friendly catheter delivery system. Humacyte, Inc., with funding from the DoD, is working on an off-the-shelf, human tissue-engineered vascular prosthesis. This decellularized human collagen-based vascular tissue technology has performed well in both canine and baboon studies, and the company is working toward a regulatory filing to enable a clinical trial.

Reducing Burn Progression with Topical Delivery of Conjugates that Target Inflammation

Partial-thickness burn injuries often progress with time, leading to necrotic expansion and an increased chance of secondary complications. The AFIRM is funding researchers at the USAISR to determine whether the topical application of an antibody targeting the pro-inflammatory cytokine tumor necrosis factor-alpha (TNF-α) conjugated to hyaluronic acid (HA) can reduce further necrosis by modulating inflammation locally in a partial-thickness rat burn model. They found that HA treatment alone reduced burn progression by nearly 30%, but anti-TNF-α-HA reduced it by approximately 70%. They also observed decreased infiltration of macrophages in anti-TNF-α-HA-treated sites compared to controls, suggesting a reduction in overall inflammation at all time points. These results suggest that local targeting of TNF-α may be an effective strategy for preventing progression of partial-thickness burns.

Reset – Transplants

Advancing Reconstructive Transplantation Research

Composite tissue transplantation offers wounded warriors with severe disfigurement and dysfunction another option for restorative surgery over standard reconstructive treatments. With funding from the AFIRM, progress is being made in the area of reconstructive transplantation at two sites. Scientists at Brigham and Women's Hospital have successfully performed four facial transplantations. All four patients are experiencing return of sensation and motor function to the transplanted tissue. Researchers at the University of Pittsburgh Medical Center are using structural fat grafting to improve craniofacial appearance after trauma. While several patients with military affiliation have been treated thus far, the study is in progress and analyses of results are pending.

Optimizing Hand Transplantation Research

With funding from the AFIRM, surgeons at the University of Louisville; Jewish Hospital and St. Mary's Healthcare; and Kleinert, Kutz, and Associates are performing allogeneic hand transplantation to restore function to a nonfunctioning or amputated hand. To date, 10 procedures have been conducted on 6 patients (4 bilateral and 2 unilateral procedures), and, remarkably, one of these patients is more than 10 years post-surgery. Researchers at these institutions are also studying the mechanisms of tolerance induction to allogeneic tissue grafts in animal models. In a separate study, researchers at the JHU School of Medicine and the University of Pittsburgh have developed a protocol for hand transplantation using a patient's own bone marrow with the addition of the CTLA4Ig fusion protein, a reagent that has been found to exert an immunosuppressive effect without causing major toxicity. This protocol minimizes the amount of immunosuppressive therapy required following a transplant. Hand transplants on six patients have been completed to date, and all patients have been maintained on a single immunosuppressive drug at low levels. They continue to have increased motor and sensory function in their transplanted hands, correlating with their level of amputation, time after transplant, and participation in physical therapy. These studies can potentially lead to minimization or elimination of immunosuppressive drug regimens currently required to prevent rejection of transplanted tissues.

Reset – Prosthetics/ Rehabilitation

Developing a Neural Interface for Powered Lower Limb Prostheses

With funding from TATRC, researchers at the Rehabilitation Institute of Chicago have developed a neural interface for controlling lower extremity prostheses. Their interface uses muscle pattern recognition software to discern user intent from body-worn electromyography electrodes. Patients with targeted muscle reinnervation in combination with this neural interface can expect even greater control. In targeted muscle reinnervation, the residual nerves of an amputated limb are transferred to available muscles. The resultant electromyography signals represent the brain's motor commands to the missing limb and are used to control the prosthesis. The outcomes of this ongoing study will improve the user-intent control of lower extremity prostheses so that users can simply think about what they want the leg to do, and it will do it. In a technology demonstration in November 2012, a patient from the Rehabilitation Institute who had lost his right leg in a motorcycle accident climbed the stairs of the 103-story Willis Tower in Chicago using the neural interface.

Studying Heterotopic Ossification (HO) in Combat Amputees

HO refers to the process of excess bone that grows in soft tissues. It frequently occurs in residual limbs of amputees following blast injuries in Iraq and Afghanistan, and it can interfere with the use of prosthetics and walking and can delay patient rehabilitation. Scientists do not know why HO produces debilitating symptoms in some patients but not in others. With funding from the NMRC, researchers at the NHRC studied symptomatic and/or radiographic evidence of HO in a small series of combat amputees (27 patients/33 limbs). They reviewed patient records and conducted physician interviews for evidence of HO symptoms (pain during prosthetic use, skin breakdown). They found that HO-related symptoms occurred in 10 of the 33 residual limbs. Radiographs were available for 25 of the 33 limbs, and a physician identified at least moderate HO in 15 of the radiographs. However, 5 of the 15 patients who showed at least moderate radiographic HO did not report adverse symptoms. Five individual patient histories described HO onset, symptoms, treatments, and outcomes. These case histories illustrated how HO location, relative to pressure-sensitive/pressure-tolerant areas of the residual limb, may determine whether patients experienced symptoms. These histories also revealed the novel and uncommon finding of potential benefits of HO for prosthetic suspension.

Enhancing Soldier Performance and Brain Repair Using Haptic Virtual Reality Training

With funding from TATRC, researchers at the University of Texas at Dallas are using a haptic (i.e., tactile feedback) virtual reality training environment with continuous EEG monitoring to train young persons to improve their response time and decision-making for visuomotor tasks. This approach to training is guided by neurobiological principles of use-dependent neuroplasticity underlying reorganization of the brain after injury. These training paradigms are being used to improve visuomotor performance in normal individuals, measure these brain state changes with training through EEG markers, and improve performance in TBI patients who were impaired in these functions as a result of blast-related or other injuries. This approach is also being applied to improving and preserving performance under stressful conditions, which is referred to as resilience. During the past year, the researchers were able to record reliable evoked response potential markers of training using visual-haptic paradigms. When the training regimen was increased in both visual and haptic complexity, the researchers found significantly decreased reaction times for the difficult task. They observed no significant changes in evoked response potentials in simple training paradigms.

Chapter 8

Way Forward

The DoD Blast Injury Research Program will continue to coordinate and expedite prevention, mitigation, and treatment strategies for blast-related injuries. A number of existing and planned initiatives within the PCO during the next few years will support this goal. In addition, priority areas for blast injury-related R&D are identified below.

Key Initiatives

The MHS BIPSR Process. The Blast Injury Research PCO has developed an unbiased, inclusive, stakeholder-driven process for identifying and assessing MHS Blast Injury Prevention Standards that support weapon system health hazard assessments, combat platform occupant survivability assessments, and protection system development. Next steps include establishing a blast injury topic prioritization process, selecting an initial blast injury type and specific standard to be evaluated, and developing strategies for staffing the recommendations to ASD(HA) for approval and for codifying the approved standards. Implementation of the BIPSR Process is scheduled to begin by the end of the 2QFY13.

International State-of-the-Science Meeting Series. Blast-related injuries continue to dominate the spectrum of injuries sustained by our Nation's warfighters. Major limb trauma sustained in the military results in significant long-term disability. The decision whether to salvage or amputate an injured limb has generated much controversy in the literature, with studies to support advantages of each approach.

The PCO will conduct its fourth meeting in the State-of-the-Science Meeting Series in the 2QFY14; the topic will be Limb Salvage and Rehabilitation. This meeting will be held in conjunction with the VA, the Traumatic Extremity Injury and Amputation Center of Excellence, and the Center for the Intrepid. The PCO will again bring together top researchers from around the world—representing academia, industry, other Federal organizations, and the DoD—to help identify and focus future DoD research investment on resolving critical knowledge gaps.

NATO HFM Panels. The PCO will chair the NATO HFM-234 Technical Activity on "Environmental Toxicology of Blast Exposures: Injury Metrics, Modeling, Methods and Standards." Planning is underway for a July 2013 kickoff meeting for the activity. The HFM-234 technical team will address a wide range of topics, including physics-based modeling of animals and man in relevant blast environments, blast exposure monitoring methods and metrics, and standardized protocols for blast injury research. In addition to technical exchange, key outcomes are expected to include standardized animal models and blast exposure methodologies, such as shock tubes, and toxicology research protocols that can be adopted by research and technology programs across NATO.

JTAPIC Program. As an Army non-materiel enduring capability, the JTAPIC Program will continue to enhance warfighter survivability and fulfill key EA responsibilities. The JTAPIC Program will continue to collaborate with, and provide actionable information to, vehicle program managers and TRADOC capability managers. The program will assist with force modernization decisions, promote and enhance joint Service information sharing and collaboration, and provide targeted analysis and information in response to specific RFIs from DoD customers. Battlefield exposure sensor data analysis will continue to determine if sensor data can be used to monitor events and predict injuries. The Program will work with international partners through the Technical Cooperation Program, the 5P SNR(A), NATO, and other venues to develop similar data collection and integration capabilities for their militaries and enable information sharing. The JTAPIC Program intends to participate in the White House's efforts to develop policy regarding PPE and injury mitigation for first responders.

DoD Brain Injury Computational Modeling Expert Panel. The Blast Injury Research PCO is working to establish the framework for the computational blast-induced mTBI modeling enterprise. Ultimately, this enterprise will help set research agendas, identify priorities, and enable the sharing of information and resources. The Panel envisions a working roadmap for the development of a computational model of non-impact, blast-induced mTBI. The intent is to publish the results of the panel's efforts in a peer-reviewed journal.

Second Blast Injury Research Planning Meeting. The first Blast Injury Research Planning Meeting was held at Fort Detrick, Maryland, in July 2006 to summarize the state of the science for blast injury and map out gaps in the then current and planned DoD investment in blast injury research. The PCO anticipates the need to conduct a second Blast Injury Research Planning Meeting to assess what has been accomplished, what is underway or planned, and what blast injury research gaps remain since the original planning meeting held in July 2006.

Access to Historical Blast Injury Research Data to Support Current and Future Blast Injury Research. More than a decade ago, the MOMRP at USAMRMC recovered the original data from an extensive blast injury research program that took place at the Blast Test Site located on Kirtland Air Force Base in Albuquerque, New Mexico, from 1951–1998. This blast injury research program is generally recognized as the world's most extensive. It included a vast number of experiments under a wide range of blast conditions with more than 13 animal species. Most of these types of experiments can never be done again under current laws and regulations governing the ethical use of animals in research. The PCO recognizes the tremendous value of these historical blast injury research data and will seek to establish a mechanism for making these blast bioeffects data available in a format that can be used by the research community to solve current and future blast injury problems.

Blast Injury Program Coordinating Board. To improve coordination and ensure the PCO is meeting the needs of its customers, the PCO will seek to establish a Blast Injury Program Coordinating Board with representation from all of the stakeholder organizations identified in DoDD 6025.21E, the governing directive for the DoD Blast Injury Research Program.

Research and Development

The goal for blast injury R&D is to continue to identify, prioritize, develop, and ultimately field solutions to improve the military's capability to prevent and respond to blast injuries. Overarching goals for the primary focus areas are:

- **Injury Prevention:** Reduce the number and severity of blast-related injuries,
- **Acute Treatment:** Reduce morbidity and mortality from blast injuries and improve battlefield capabilities for treating blast injuries, and
- **Reset:** Reduce the recovery time, and increase the return-to-duty rate and quality of life for Service members with blast injuries.

Specific areas of concentration are identified within each of these focus areas.

Injury Prevention

- **Injury Mechanisms.** Research on injury mechanisms is a critical aspect whose discoveries serve as the basis for development of future products in multiple areas from prevention through acute treatment and reset. As an example, mechanisms of TBI, particularly mTBI, and the effects of multiple blast exposures are not well understood. Elucidating blast injury mechanisms will help identify new targets and approaches for medical products and strategies. These products may include new injury models and standards to support protective equipment development, safer weapons systems, new diagnostic capabilities, new treatment strategies, drugs and devices for injuries, and rehabilitation. Future research is anticipated to address mechanisms of soft and hard tissue injuries, trauma to the sensory systems, and blast wave interactions with the body (including in conjunction with protective equipment).

- **Injury Models.** Future research in this area is expected to lead to computational and animal models of blast injuries. These models will be used to study blast injury mechanisms and identify novel targets for mitigation and treatment strategies for blast injury. The development of models for neural injury, particularly TBI, is a priority. Cross-species correlations will be important to ensure that candidate strategies developed in animal models are transferable to humans, as positive results in prior models have not always predicted success in humans. Many models are under development; it is critical that they be appropriately validated for use.
- **Protective Equipment.** Research will continue to support the development of biomedically valid criteria and standards for protective equipment, such as body armor and helmets, and their incorporation into vehicle platforms (e.g., seats, restraints, and vehicle armor and blast mitigation systems). Injury criteria and standards will be sent to the developers of vehicle and protective equipment for use in creating those systems. Priority areas of interest are reducing injuries, from UBB to vehicles, and reducing the injury and severity of TBI through head protection systems. Protection of hearing and vision will remain an important avenue of research.

Acute Treatment

- **Epidemiology.** Epidemiological research will continue to identify and analyze injury trends and treatment outcomes. Such information is critical to determining the required military capabilities needed to prevent, mitigate, and treat blast injuries, as well as directing and prioritizing research to fill gaps in knowledge and capability.
- **Diagnostics.** This research area includes technologies to diagnose and monitor blast injuries and injury/healing parameters during treatment, as well as technologies to monitor blast exposure and predict the likelihood of injury. Technologies and strategies are being researched to provide the basis for developing improved monitors and outcome predictors for surgery, treatment, and rehabilitation. Various projects are underway to develop helmet-mounted and body-worn sensors for blast injury. Data will be analyzed by the JTAPIC Program and others to determine whether sensor data can be used to accurately quantify exposure and predict injury potential and the need for medical evaluation.
- **Hemorrhage and Blood.** Research is expected to be directed at non-compressible hemorrhage (such as from internal organ damage and bleeding), controlling the cascade of injury following severe hemorrhage (e.g., coagulopathy), and the availability of replacement blood products and components. Development of treatment strategies to counteract coagulopathies using existing blood components will continue. Alternatives to blood components and shelf-stable components are needed to ensure sufficient supplies of blood products for military operations. Diagnostic tools are needed to address physiological and hemodynamic parameters following significant blood loss or trauma and while under treatment. In addition, the development of rapid screening technologies is necessary to ensure the safety of whole blood supplies procured in the far-forward field environment, as logistical issues may prevent the availability of sufficient pre-screened blood.

- **Wound Repair and Stabilization.** Research is needed to develop and evaluate new strategies and technologies for treating and stabilizing wounds on the battlefield, from self/buddy aid and the first responder through surgical repair and stabilization at the combat support hospital. Improvements in the early phase or battlefield treatments for injuries could promote better wound healing and tissue regrowth and thus lead to improved long-term outcomes for patients, particularly in areas of scar formation and craniomaxillofacial injury. Other areas of research include developing treatments for trauma to the sensory systems (e.g., hearing and vision), including strategies to reduce further functional loss following exposure and to restore function.
- **Wound Infection.** Wounds incurred from blast-related incidences are highly traumatic and can result in injuries to multiple organs, disruption to bone and soft tissue, and extensive wound contamination. Developing therapies to prevent and treat bacterial, viral, and fungal infections remains a major challenge in the treatment of severe wounds due to the increasing incidence of drug-resistant pathogens. Future efforts in this area will focus on research to develop tools and practices that prevent infections and/or guide clinical wound management decisions, including the development of tools for rapid and early detection of multidrug-resistant organisms and infection, developing FDA-approved therapies, and using biomarkers or other molecular signatures to monitor wound healing and determine optimal treatment paths.
- **TBI Treatment.** While significant amounts of research have been conducted on TBI, very few diagnostic tools, treatments, or rehabilitation strategy development efforts have resulted in successful clinical trials. In August 2012, the President directed multiple Federal agencies to develop a National Research Action Plan, that includes strategies to improve early diagnosis and treatment effectiveness for PTSD and TBI. Validated animal and computational models are needed, along with appropriate experimental apparatus and conditions for exposing animals to blast. These models should mimic the human disease and allow study of TBI as well as identification and development of treatment strategies. Improved clinical trial methodologies and validated tools are needed to document treatment effects without confounding variables. Efforts are underway to determine whether data from blast exposure sensors can be used to predict injury, particularly for mild or delayed effects. Major knowledge gap areas that are being addressed include developing diagnostic tools and criteria, establishing biomarkers and treatment outcome measures for TBI, understanding the mechanisms and long-term effects of TBI, understanding the impact of pre-existing and co-occurring conditions on outcome, determining the relationship between multiple blast exposures and TBI, finding ways to harness neural repair mechanisms, developing treatment and rehabilitation products, and identifying strategies to improve psycho-social impacts of living with TBI.

Reset

- **Regenerative Medicine.** Regenerative medicine research will focus on the areas of peripheral nerve injury, skin injury, scarless wound healing, vascular injury, and composite tissue allotransplantation/immunomodulation. Strategies are needed for regeneration of nerves over long distances, improved reliability of nerve regeneration, development of alternatives to nerve grafts, improved re-innervation of organs and tissues, and improved functional outcomes. Future skin injury research will focus on the development of technologies that address full thickness burns and that better address the complex architecture of the face and hands as well as next-generation products that target improvement in functional/aesthetic outcomes. Strategies are needed to provide wound healing with reduced scarring, such as controlling inflammatory response and fibrosis, particularly for deep burn injuries. Research is also needed for vascular scaffolds for regrowth, alternatives to autografts, and improving the vascularization of large tissue constructs.

- **Transplants.** Research in transplants should continue to focus on developing strategies that reduce the consequences (adverse effects and toxicity) of long-term immunosuppressive therapy to prevent transplant rejection and improve the functioning of the transplanted tissue. Limb and face transplants continue to be priorities; however, there is a limited patient population need. Therefore, research is also directed at strategies and technologies to allow the transplantation of smaller complex tissue units (e.g., portions of the extremities and face, or internal tissues) to restore function.
- **Prosthetics.** Future prosthetics research will address improvements in prosthetic function through improved human-device interface. For example, investigations will focus on enhanced exteroreceptive sensor integration where more information is obtained from the environment and the user for ease of limb function or the integration of neural signals and mechanical devices for user-intent control that make limb movement more natural. Other topics will include improving comfort and limb health at the socket and addressing the high rejection rates seen with upper-extremity prostheses. Prosthetic-related research will also focus on identifying and addressing the long-term health consequences of amputation, such as HO, reduction in bone mineral density, the development of osteoarthritis, and reduced mobility.
- **Rehabilitation.** Research is needed to address the rehabilitation of neuromusculoskeletal injuries, which includes optimizing rehabilitation regimens; developing assessment tools and outcome predictors; the use and human-device interface of prosthetics and orthotics; improving lost function due to burn and scar contracture; spinal cord injuries; secondary health effects (such as osteoarthritis, HO, low back pain, fractures, and cardiovascular disease); and reintegration strategies for return-to-duty or transition to civilian life. Improved pain management strategies are needed at all levels of care from the battlefield through rehabilitation.

Coordination by the PCO

In carrying out its research coordination responsibilities, the PCO will facilitate collaborative research among DoD laboratories and laboratories of other Federal agencies, academia, industry, and the international communities. These research collaborations will enable the DoD to leverage resources and take full advantage of the body of knowledge residing within and outside of the DoD to solve complex blast injury problems and to establish and maintain a fully coordinated DoD blast injury research program as envisioned by Congress and directed by the Secretary of Defense.

Appendix A
Acronym List

2Q	2nd Quarter
5P SNR(A)	Five Power Senior National Representatives Army
AAAP	Anti-Armor Analysis Program
ACH	Advanced Combat Helmet
AFIRM	Armed Forces Institute of Regenerative Medicine
AFMES	Armed Forces Medical Examiner System
AHP	Army Hearing Program
AIM	Axon Injury Micro-Compression
AIS	Abbreviated Injury Scale
ANAM4	Automated Neuropsychological Assessment Metric 4
AOC	Alteration of Consciousness
APL	Applied Physics Laboratory
AR	Army Regulation
ARL	US Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASBREM	Armed Services Biomedical Research Evaluation and Management
ASD	Acute Stress Disorder
ASD(HA)	Assistant Secretary of Defense for Health Affairs
ASD(R&E)	Assistant Secretary of Defense for Research and Engineering
ATC	Aberdeen Test Center
ATD	Anthropometric Test Device
ATEC	Army Test and Evaluation Command
AWG	Asymmetric Warfare Group
BBB	Blood-Brain Barrier
BECIR	Blast Exposure and Concussion Incident Report
BG	Brigadier General
BIPSR	Blast Injury Prevention Standards Recommendation
bTBI	Blast-Induced TBI
BVFT	Battlefield Vehicle Forensics Team
Ca++	calcium ion
CCC	Combat Casualty Care
CCCRP	Combat Casualty Care Research Program
CENC	Chronic Effects of Neurotrauma Consortium
CENTCOM	US Central Command
CJCS	Chairman Joint Chiefs of Staff
CJTF	Combined Joint Task Force
COCOM	Combatant Commanders
CoEs	Centers of Excellence
CONUS	Continental United States
CPT	Captain
CRM	Clinical and Rehabilitative Medicine
CSI	Congressional Special Interest
CTE	Chronic Traumatic Encephalopathy
CTTSO	Combating Terrorism Technology Support Office
D-AA	D-Amino Acid
DARPA	Defense Advanced Research Projects Agency
DCoE	Defense Centers of Excellence
DHP	Defense Health Program
DIAT	Dismounted Incident Analysis Team
DMMPO	Defense Medical Materiel Program Office
DoD	Department of Defense
DoDD	DoD Directive
DoDI	DoD Instruction
DOT&E	Director, Operational Test and Evaluation
DSTI	Deep Soft Tissue Infection
DTI	Diffusion Tensor Imaging
DTM	Directive-Type Memorandum
DVBIC	Defense and Veterans Brain Injury Center
DVCIPM	Defense and Veterans Center for Integrative Pain Management
EA	Executive Agent
ECH	Enhanced Combat Helmet
ECM	Electronic Countermeasure
EEG	Electroencephalograph

EHR	Electronic Health Record
EMED	Expeditionary Medical Encounter Database
EOD	Explosive Ordnance Disposal
FDA	US Food and Drug Administration
FDP	Freeze-Dried Plasma
FEM	Finite Element Model
FFP	Fresh Frozen Plasma
FOA	Forward Operational Assessments
FPI	Fluid Percussion Injury
FY	Fiscal Year
Gen	Generation
GTRI	Georgia Tech Research Institute
GVS&OP	Ground Vehicle Survivability and Occupant Protection
HA	Hyaluronic Acid
HBO2	Hyperbaric Oxygen
HFM	Human Factors and Medicine
HIFU	High-Intensity Focused Ultrasound
HIT	Human Injury Treatment
HMS	Height Management System
HMSS	Helmet-Mounted Sensor System
HO	Heterotopic Ossification
I-BESS	Integrated Blast Effect Sensor Suite
IEDs	Improvised Explosive Devices
IEWG	Incident Exploitation Working Group
IFAK	Individual First Aid Kit
IIPTs	Integrating Integrated Product Teams
IPMC	Interdisciplinary Pain Management Center
JFAK	Joint First Aid Kit
JHU	Johns Hopkins University
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JPCs	Joint Program Committees
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat
KIA	Killed In Action
kPa	Kilopascal
LFT&E	Live-Fire Test and Evaluation
LTG	Lieutenant General
M&S	Modeling and Simulation
MCOTEA	Marine Corps Operational Test & Evaluation Activity
MCVV	Mortar Carrier Vehicle Double V-Hull
MEDEVAC	Medical Evacuation
MEG	Magnetoencephalography
MG	Major General
MHS	Military Health System
MIDRP	Military Infectious Diseases Research Program
MIL-STD	Military Standard
miRNA	Micro Ribonucleic Acid
MIT	Massachusetts Institute of Technology
MOM	Military Operational Medicine
MOMRP	MOM Research Program
MRAP	Mine Resistant Ambush Protected
mTBI	mild TBI
MTF	Military Treatment Facility
NATO	North Atlantic Treaty Organization
NGIC	National Ground Intelligence Center
NHRC	Naval Health Research Center
NICoE	National Intrepid Center of Excellence
NIH	National Institutes of Health
NMRC	Naval Medical Research Center
NRC	National Research Council
NRP	Nonionizing Radiation Program
NSS	National Security Staff
NSWCCD	Naval Surface Warfare Center, Carderock Division
OC	Occupant-Centric
OCO	Overseas Contingency Operation
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ONR	Office of Naval Research
ORSA	Operations Research and Systems Analysis
OSD	Office of the Secretary of Defense
OTSG	Office of the Surgeon General
PASTOR	Patient Assessment and Outcomes Registry
PB	President’s Budget
PBI	Primary Blast Injuries
PBBI	Penetrating Ballistic-like Brain Injury

PCO	Program Coordinating Office
PCS	Postconcussive Syndrome
PD	Parkinson's Disease
PETN	Pentaerythritol Tetranitrate
PEO	Program Executive Office
PETN	Pentaerythritol Tetranitrate
PM	Project Manager
PMO	Program Management Office
PMHS	Post-Mortem Human Subject
PM ICE	Program Manager Infantry Combat Equipment
PM SPE	Product Manager Soldier Protective Equipment
PM SPIE	Product Manager Soldier Protection and Individual Equipment
PPE	Personal Protective Equipment
PPS	Pelvic Protection System
PROMIS	Patient-Reported Outcomes Measurement Information System
PTSD	Posttraumatic Stress Disorder
POG	Protective Outer Garment
PUG	Protective Under Garment
R&D	Research and Development
RACs	Research Advisory Committees
RDECOM	Research, Development and Engineering Command
RDT&E	Research, Development, Testing, and Evaluation
RFI	Request for Information
RMI	Reflectance Medical, Inc.
R-TEEMS	Real-time EEG Monitoring System
RTG	Research and Technology Organization Task Group
S&T	Science and Technology
SAF	Small Arms Fire
SBIR	Small Business Innovation Research
SecAF	Secretary of the Air Force
SecArmy	Secretary of the Army
SecNav	Secretary of the Navy
siRNA	Small Interfering Ribonucleic Acid
SLAD	Survivability/Lethality Analysis Directorate
TARDEC	Tank Automotive Research, Development and Engineering Center
TATRC	Telemedicine and Advanced Technology Research Center
TBI	Traumatic Brain Injury
TCCC	Tactical Combat Casualty Care
TGI	Toxic Fire Gas Inhalation
TNAP	Tissue-Nonspecific Alkaline Phosphatase
TNF-α	Tumor Necrosis Factor-Alpha
TRADOC	Training and Doctrine Command
TSWG	Technical Support Working Group
TTPs	Tactics, Techniques, and Procedures
UBB	Under Body Blast
UK	United Kingdom
UNL	University of Nebraska-Lincoln
USAARL	US Army Aeromedical Research Laboratory
USAF	US Air Force
USAISR	US Army Institute of Surgical Research
USAMEDCOM	US Army Medical Command
USAMRMC	US Army Medical Research and Materiel Command
USFOR-A	US Forces Afghanistan
USMC	US Marine Corps
USSOC	US Special Operations Command
USUHS	Uniformed Services University of the Health Sciences
UVA	University of Virginia
VA	US Department of Veterans Affairs
VCSA	Vice Chief of Staff of the Army
VT	Virginia Polytechnic and State University
V-Xtract	Vehicle Extrication Trainer
WIA	Wounded In Action
WIAMan	Warrior Injury Assessment Manikin
WMRD	Weapons and Materials Research Directorate
WRAIR	Walter Reed Army Institute of Research
WRNMMC	Walter Reed National Military Medical Center
WSS	Wound Stasis System

WSU	Wayne State University
WTC	Warrior Transition Command
WTU	Warrior Transition Unit
α-SMA	Alpha Smooth Muscle Actin
Ω-3 PUFA	Omega-3 Polyunsaturated Fatty Acid

Appendix B
DoDD 6025.21E

Department of Defense

DIRECTIVE

NUMBER 6025.21E
July 5, 2006

USD(AT&L)

SUBJECT: Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries

References: (a) Section 256 of Public Law 109-163, "National Defense Authorization Act for Fiscal Year 2006"[1]
(b) DoD Directive 5101.1, "DoD Executive Agent," September 3, 2002
(c) DoD Directive 5134.3, "Director of Defense Research and Engineering (DDR&E),"November 3, 2003
(d) DoD Directive 5025.1, "DoD Directives System," March 2005
(e) through (g), see Enclosure 1

1. PURPOSE

This Directive:

1.1. Implements Reference (a) by establishing policy and assigning responsibilities governing coordination and management of medical research efforts and DoD programs related to prevention, mitigation, and treatment of blast injuries.

1.2. Designates the Secretary of the Army, in compliance with Reference (a) and consistent with Reference (b), as the DoD Executive Agent (DoD EA) for Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries according to Reference (b).

1.3. Establishes the Armed Services Biomedical Research Evaluation and Management (ASBREM) Committee. The ASBREM Committee serves to facilitate coordination and prevent unnecessary duplication of effort within DoD biomedical research and development and associated enabling research areas, to include serving as the forum for implementation of subsections (d) and (g) of Reference (a).

[1] Federal legislative information is available through the Library of Congress THOMAS site, http://thomas.loc.gov.

2. APPLICABILITY

This Directive applies to:

2.1. The Office of the Secretary of Defense, the Military Departments, the Chairman of the Joint Chiefs of Staff, the Combatant Commands, the Office of the Inspector General of the Department of Defense, the Defense Agencies, the DoD Field Activities, and all other organizational entities in the Department of Defense (hereafter collectively referred to as the "DoD Components").

2.2. Medical and associated enabling research supported by any DoD Component for prevention, mitigation, and treatment of blast injuries.

3. DEFINITIONS

As used in this Directive, the following terms are defined as follows:

3.1. Blast Injury. Injury that occurs as the result of the detonation of high explosives, including vehicle-borne and person-borne explosive devices, rocket-propelled grenades, and improvised explosive devices. The blast injury taxonomy is provided at Enclosure 2.

3.2. Research. Any systematic investigation, including research, development, testing, and evaluation (RDT&E), designed to develop or contribute to general knowledge.

4. POLICY

It is DoD policy that:

4.1. DoD research related to blast injury prevention, mitigation, and treatment will be coordinated and managed by a DoD EA to meet the requirements, objectives, and standards of the DoD Military Health System as identified by the Under Secretary of Defense for Personnel and Readiness (USD(P&R)) and the unique combat casualty care requirements of the DoD Components.

4.2. Relevant research shall take maximum advantage of the scientific and technical capabilities of industry, academia, DoD Components, and other Federal Agencies.

4.3. The ASBREM Committee will be the venue for joint and cross-Service coordination specified by Reference (a).

4.4. DoD Components will gather and share medical information related to the efficacy of personal protective equipment and of vehicular equipment designed to protect against blast injury.

5. RESPONSIBILITIES AND FUNCTIONS

5.1. The Director of Defense Research and Engineering (DDR&E), under the Under Secretary of Defense for Acquisition, Technology and Logistics, according to DoD Directive 5134.3 (Reference (c)), shall:

5.1.1. Plan, program, and execute the functions and reports mandated for the DDR&E by Reference (a).

5.1.2. Have the authority to publish DoD Issuances consistent with Reference (d) for implementation of this Directive.

5.1.3. Establish, as needed, procedures to ensure that new technology developed under this Directive is effectively transitioned and integrated into systems and subsystems and transferred to and firmly under the control of the DoD Components.

5.1.4. Chair the ASBREM Committee to coordinate DoD biomedical research (see Enclosure 3 for additional detail), and employ that entity to facilitate the DoD EA's coordination and oversight of blast-injury research as specified in Reference (a).

5.1.5. Serve as the final approving authority for DoD blast-injury research programs.

5.1.6. Oversee the functions of the DoD EA and conduct/report on related periodic assessments (per Reference (a)).

5.2. The Assistant Secretary of Defense for Health Affairs (ASD(HA)), under the USD(P&R), shall:

5.2.1. Assist the DDR&E, the DoD EA, and the Director, Joint Improvised Explosive Devices Defeat Organization (JIEDDO), with identification of related operational and research needs, assessment of relevant research efforts, and coordination of planning to resolve capability gaps through focused research efforts.

5.2.2. Be the approving authority for Military Health System prevention and treatment standards developed and proposed by the DoD EA.

5.2.3. Appoint appropriate representatives to related coordinating boards or committees established by the DoD EA.

5.2.4. Ensure that the information systems capabilities of the Military Health System support the DoD EA and the functions specified by this Directive.

5.2.5. Serve as Co-chair of the ASBREM Committee. (See Enclosure 3 for additional detail.)

5.3. The Secretary of the Army is hereby designated as the DoD EA for Medical Research for Prevention, Mitigation, and Treatment of Blast Injuries, consistent with Reference (a), to coordinate and manage relevant DoD research efforts and programs, and in that role shall:

5.3.1. Give full consideration to the Research and Engineering (R&E) needs of the DoD Components and the Director, JIEDDO, addressing those needs/requirements by:

5.3.1.1. Maintaining a DoD technology base for medical research related to blast injuries and based on the DDR&E-approved program for the DoD Components.

5.3.1.2. Performing programming and budgeting actions for all blast-injury research to maintain the R&E programs based on DDR&E-approved priorities of the DoD Components.

5.3.1.3. Programming and budgeting for blast-injury research based on analysis and prioritization of needs of the DoD Components, consistent with paragraph 5.1 of this Directive.

5.3.1.4. Executing the approved DoD blast-injury research program consistent with DoD guidance and availability of annual congressional appropriations.

5.3.2. Provide medical recommendations with regard to blast-injury prevention, mitigation, and treatment standards to be approved by the ASD(HA).

5.3.3. Coordinate DoD blast-injury-research issues with the staffs of the DDR&E, the ASD(HA), and the Director, JIEDDO.

5.3.4. Support the development, maintenance, and usage of a joint database for collection, analysis, and sharing of information gathered or developed by the DoD Components related to the efficacy of theater personal protective equipment (including body armor, helmets, and eyewear) and vehicular equipment designed to protect against blast injury.

5.3.5. Appoint a medical general or flag officer representative to the ASBREM Committee.

5.3.6. Ensure that information is shared as broadly as possible except where limited by law, policy, or security classification and that data assets produced as a result of the assigned responsibilities are visible, accessible, and understandable to the rest of the Department as appropriate and in accordance with Reference (e).

5.4. The Secretaries of the Navy and the Air Force shall:

5.4.1. Forward their respective approved blast-injury medical R&E requirements to the DoD EA for consideration and integration.

5.4.2. Appoint medical general or flag officer representatives to the ASBREM Committee and appoint representatives to any other coordination, oversight, or assessment board established by DDR&E or the DoD EA.

5.4.3. Coordinate with other DoD Components on the assignment of Joint Technical Staff Officers to Army medical research entities, research and acquisition organizations, or installations for coordination of research programming and execution needs pertaining to their Component.

5.4.4. Provide an appropriate system for identification, verification, prioritization, and headquarters-level approval of their respective blast-injury R&E requirements before submission to the DoD EA.

5.5. The President of the Uniformed Services University of the Health Sciences (USUHS), under the ASD(HA) and USD(P&R), shall:

5.5.1. Ensure that education relating to blast-injury prevention, mitigation, and treatment is included in the USUHS medical and continuing education curriculum and programs.

5.5.2. Appoint a representative to any coordination, oversight, or assessment board established by DDR&E or the DoD EA.

5.6. The Chairman of the Joint Chiefs of Staff shall:

5.6.1. Coordinate input to the DoD EA and ensure integration of the requirements processes of the Joint Capabilities Integration and Development System[2] with the processes employed under this Directive.

5.6.2. Appoint a relevant senior representative to the ASBREM Committee.

5.6.3. Appoint representatives to organizational entities of the ASBREM Committee and to any other coordination, oversight, or assessment board established by DDR&E or the DoD EA.

5.7. The Commander, U.S. Special Operations Command shall establish procedures and processes for coordination of relevant Defense Major Force Program 11 activities with those planned, programmed, and executed by the DoD EA and shall also:

5.7.1. Forward that command's approved blast-injury R&E requirements for consideration and integration to the DoD EA.

5.7.2. Appoint representatives to organizational entities of the ASBREM Committee, as appropriate, and to any other coordination, oversight, or assessment board established by DDR&E or the DoD EA.

[2] CJCSI 3170.01E, "Joint Capabilities Integration and Development System," May 11, 2005, is available at http://www.dtic.mil/cjcs_directives/cjcs/instructions.htm.

5.7.3. Coordinate with the command on the assignment of Joint Technical Staff Officers to Army medical research entities, research and acquisition organizations, or installations for coordination of research programming and execution needs.

5.7.4. Provide an appropriate system for identification, verification, and headquarters-level approval of that command's blast-injury R&E requirements before submission to the DoD EA.

5.8. The Director, JIEDDO, consistent with Reference (f), shall:

5.8.1. Support development, maintenance, and usage of a joint database for collection, analysis, and sharing of information gathered or developed by DoD Components related to the efficacy of theater personal protective equipment (e.g., body armor, helmets, and eyewear) and vehicular equipment designed to protect against blast-injury.

5.8.2. Appoint representatives to organizational entities of the ASBREM Committee, as appropriate, and to any other coordination, oversight, or assessment board established by DDR&E or the DoD EA.

5.8.3. Assist the DoD EA, the DDR&E, and the ASD(HA) with identification of related operational and research needs, assessment of relevant research efforts, and coordination of planning to resolve capability gaps through focused research efforts.

6. AUTHORITY

The DoD EA identified by this Directive is hereby delegated authority to do the following:

6.1. Obtain reports and information, consistent with the policies and criteria of DoD Directive 8910.1 (Reference (g)), as necessary, to carry out assigned responsibilities and functions.

6.2. Communicate directly with the Heads of the DoD Components, as necessary, to carry out assigned functions, including the transmission of requests for advice and assistance. Communications to the Military Departments shall be transmitted through the Secretaries of the Military Departments, their designees, or as otherwise provided in law or directed by the Secretary of Defense in other DoD issuances. Communications to the Commanders of the Combatant Commands shall normally be transmitted through the Chairman of the Joint Chiefs of Staff.

6.3. Communicate with other Federal Agencies, representatives of the Legislative Branch, members of the public, and representatives of foreign governments, as appropriate, in carrying out assigned responsibilities and functions. Communications with representatives of the Legislative Branch shall be coordinated with the Assistant Secretary of Defense for Legislative Affairs and the Under Secretary of Defense (Comptroller)/Chief Financial Officer, as appropriate, and be consistent with the DoD Legislative Program.

7. <u>EFFECTIVE DATE</u>

This Directive is effective immediately.

Gordon England

Enclosures – 3
- E1. References, continued
- E2. Taxonomy of Injuries from Explosive Devices
- E3. ASBREM Committee

E1. ENCLOSURE 1

REFERENCES, continued

(e) DoD Directive 8320.2, "Data Sharing in a Net-Centric Department of Defense," December 2, 2004
(f) DoD Directive 2000.19E, "Joint Improved Explosive Device Defeat Organization (JIEDDO)," February 14, 2006
(g) DoD Directive 8910.1, "Management and Control of Information Requirements," June 11, 1993

E2. ENCLOSURE 2

TAXONOMY OF INJURIES FROM EXPLOSIVE DEVICES

E2.1.1. Primary. Blast overpressure injury resulting in direct tissue damage from the shock wave coupling into the body.

E2.1.2. Secondary. Injury produced by primary fragments originating from the exploding device (preformed and natural (unformed) casing fragments, and other projectiles deliberately introduced into the device to enhance the fragment threat); and secondary fragments, which are projectiles from the environment (debris, vehicular metal, etc.).

E2.1.3. Tertiary. Displacement of the body or part of body by the blast overpressure causing acceleration/deceleration to the body or its parts, which may subsequently strike hard objects causing typical blunt injury (translational injury), avulsion (separation) of limbs, stripping of soft tissues, skin speckling with explosive product residue and building structural collapse with crush and blunt injuries, and crush syndrome development.

E2.1.4. Quaternary. Other “explosive products” effects – heat (radiant and convective), and toxic, toxidromes from fuel, metals, etc. – causing burn and inhalation injury.

E2.1.5. Quinary. Clinical consequences of “post detonation environmental contaminants” including bacteria (deliberate and commensal, with or without sepsis), radiation (dirty bombs), tissue reactions to fuel, metals, etc.

E3. ENCLOSURE 3

ASBREM COMMITTEE

E3.1. ORGANIZATION AND MANAGEMENT

The ASBREM Committee shall:

E3.1.1. Consist of general and flag officer and Senior Executive representatives of relevant DoD Components.

E3.1.1.1. Standing members include relevant senior officials of the DoD Components. At a minimum, the DDR&E, the ASD(HA), and representatives of the DoD Components' Acquisition Executives.

E3.1.1.2. The standing membership may be expanded by invitation of the Chair when issues require senior-level coordination outside the scope of the principal members. Such invited members will include a medical flag officer from the Joint Staff, a designee of the DoD EA specified by this Directive, the Director, JIEDDO, the Director of the Combating Terrorism Technology Support Office, and others as appropriate.

E3.1.2. Be chaired by the DDR&E or Senior Executive designee and co-chaired by the ASD(HA) or Senior Executive designee.

E3.1.3. Convene at the discretion of the Chair and Co-chair.

E3.1.4. Invite the attendance of observers from DoD boards, committees or offices, or from other Federal Agencies with interests in the deliberations of the ASBREM Committee.

E3.1.5. Establish subcommittees, Joint Technology Coordinating Groups, and other entities, as required, to facilitate and execute committee business.

E3.2. FUNCTIONS

The ASBREM Committee shall:

E3.2.1. Review medical RDT&E program plans and accomplishments for quality, relevance, and responsiveness to military operational needs, the needs of the Military Health System, and the goals of Force Health Protection.

E3.2.2. Review program plans and budgets in support of the various guidance documents relevant to National Security and to the missions and functions of the Department of Defense.

E3.2.3. Provide coordination, recommendations, and support to DoD EA(s) and other DoD officials as requested, directed, or otherwise appropriate.

For more information, visit
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