DEPARTMENT OF DEFENSE

Science and Technology Efforts and Programs Relating to the Prevention, Mitigation, and Treatment of Blast Injuries

FY10–FY11 Report to the Executive Agent

DoD Blast Injury Research Program Coordinating Office
U.S. Army Medical Research and Materiel Command

Executive Summary

The Department of Defense (DoD) continues to make tremendous advances in the coordination and advancement of medical research programs focused on the prevention, mitigation, and treatment of blast injuries. During the past 2 years, numerous collaborative research efforts undertaken throughout the DoD, academia, industry, and other governmental agencies have resulted in significant improvements to how blast-related injuries are prevented as well as how our service members are cared for.

This Report to the Executive Agent highlights the activities undertaken in fiscal years 2010 and 2011 by the Blast Injury Research Program Coordinating Office, the Joint Trauma Analysis and Prevention of Injury in Combat Program Management Office, DoD and other federal agencies, academia, industry, and international partners to advance the state of the science in blast injury prevention, mitigation, and treatment. Included in this report are brief summaries of medical research project accomplishments, a synopsis of programs within the DoD supporting blast injury medical research, and descriptions of key program coordination initiatives that are significantly improving the dissemination of blast injury research information across the DoD and advancing the state of the science to solve extraordinarily challenging blast injury problems facing our nation's warfighters.

Among the key initiatives described in this report:

- The International State-of-the-Science Meeting Series continues to bring together national and international subject matter experts to help identify blast injury knowledge gaps that will inform future research investments in these areas. Meetings have been held on tinnitus, blast dosimetry, and non-impact, blast-induced mild traumatic brain injury.
- The DoD Brain Injury Computational Modeling Expert Panel is bringing together experts from the engineering, medical research, blast physics, and clinical medicine communities to advise the DoD on the development and use of computational modeling to understand the mechanisms of non-impact, blast-induced mild traumatic brain injury and to guide the development of effective protection systems.
- The Blast Injury Prevention Standards Recommendation (BIPSR) process is supporting the development of safe weapon systems, survivable combat vehicles, and effective protection systems by advising the medical, test and evaluation, and materiel development communities on the best available, biomedically valid blast injury prevention standards.

Among the key research accomplishments reported are:

- Under the Armed Forces Institute of Regenerative Medicine, researchers at the Johns Hopkins University School of Medicine and the University of Pittsburgh developed a protocol for hand transplantation designed to minimize the amount of maintenance immunosuppressive therapy that is needed following a transplant. The research team has performed hand transplants on five patients to date.
- The Naval Health Research Center conducted a study describing repeated concussive events among U.S. military personnel and examining their subsequent health care utilization rates and services. The median time between events was 40 days, with 20% experiencing a second event within 2 weeks of the first, and 87% within 3 months. The study demonstrated that utilization rates for neurology and mental health services for repeat concussion casualties were higher than for those with a single blast-related concussive event.
- Researchers at the Johns Hopkins University Applied Physics Laboratory funded by the Office of Naval Research have developed an advanced physical surrogate called the Human Surrogate Head Model (HSHM) to facilitate investigation of blast-related traumatic brain injury. This device is constructed of biosimulant

materials, is anatomically biofidelic, and mimics the dynamics of the human head and neck during explosive blast loading. The HSHM has been successfully deployed in more than 200 live-fire and laboratory blast experiments. These studies were the first to reveal the presence of a two-phase head response to blast overpressure loading.

- University of Alabama investigators demonstrated 17-beta estradiol to be a neuroprotectant that can reduce the progressive damage following controlled fluid percussion traumatic brain injury in rats. Benefits were shown on learning tests, cerebral perfusion pressure, intracranial pressure, partial pressure of brain oxygen, and reduced progressive brain cell death compared to untreated controls.
- Investigators at Wayne State University characterized the response of the head/brain to the effects of blast waves produced by various explosions using a sophisticated, anatomically inspired, and biomechanical finite element model of the human head.
- Orthopedic surgeons and scientists from the U.S. Army Institute of Surgical Research, working with a former Special Forces medic, assisted in the evaluation of a new clamp for treating junctional bleeding. Stopping major bleeding from junctional areas of the body, such as the groin or under the arm, is a big challenge because tourniquets cannot be applied effectively to those regions. The clamp was recently cleared for use by the U.S. Food and Drug Administration and is in use by U.S. Army Special Operations Forces.

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

A decade of war has illustrated the effectiveness of conventional, low-tech blast weapons in causing catastrophic injuries and death. As technologies to protect against the effects of these weapons have advanced, new challenges, such as polytrauma with complex, but survivable wounds, have emerged. While tremendous advances in the prevention and treatment of these complex blast injuries and rehabilitation of blast-injured service members have been made during this decade, many challenges remain. Among these are challenges in the prevention, diagnosis, and treatment of brain injuries, hemorrhage control and resuscitation, blast dosimetry, psychological health and resilience, pain management, and prevention and treatment of auditory injuries, to name just a few.

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 years 2010 and 2011 and highlights significant accomplishments during this period. These accomplishments illustrate the synergies that 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 reach out to the vast biomedical research expertise that resides in other federal agencies, academia, and industry, both within the United States and in other nations.

In addition to informing the Executive Agent, this compilation of initiatives and accomplishments is intended as a means for information sharing among the many organizations that comprise the DoD Blast Injury Research Program. Information sharing encourages collaboration, prevents duplication of effort, and fulfills the underlying objective of the congressionally mandated DoD Blast Injury Research Program.

I am pleased to present this report to the Executive Agent on behalf of the vast network of dedicated people 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

> And finally, we will continue to focus on preventing injuries in the field, by constantly improving our training, our equipment, and by learning from best practices. Even as our troops carry out their vital missions in harm's way today, we have got to make sure we protect them better in the future as they fight for us.
>
> **Leon E. Panetta, Secretary of Defense, November 10, 2011**

Current 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 as the DoD EA for medical research for prevention, mitigation, and treatment of blast injuries to coordinate and manage relevant DoD research efforts and programs. 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 and associated enabling research areas. 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) delegated authority and assigned program responsibility to the Commander, U.S. Army Medical Command.

The Blast Injury Research Program Coordinating Office (PCO) was established at the U.S. Army Medical Research and Materiel Command (USAMRMC), Fort Detrick, Maryland, to assist the EA in coordinating and managing relevant DoD medical research efforts and programs related to the prevention, mitigation, and treatment of blast injuries. The PCO operates under the management of the USAMRMC and reports to the Commanders, USAMRMC and the U.S. Army Medical Command as shown in **Figure 1-1**. The PCO coordinates and leverages service, academia, and industrial investments to promote collaboration and development of medical countermeasures to prevent, mitigate, and treat blast injuries. The PCO's goal is to coordinate and expedite prevention, mitigation, and treatment strategies for blast-related 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 1-2**) to characterize such injuries.

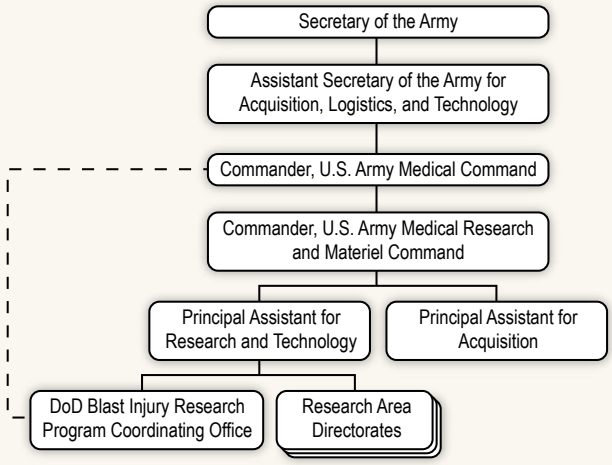


Figure 1-1. Relationship of the DoD Blast Injury Research PCO to the DoD EA

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 (BOP), can crush the body and cause internal injuries. Primary injuries are the only category of blast injuries that are unique to blast. Secondary blast injuries result when the strong blast winds

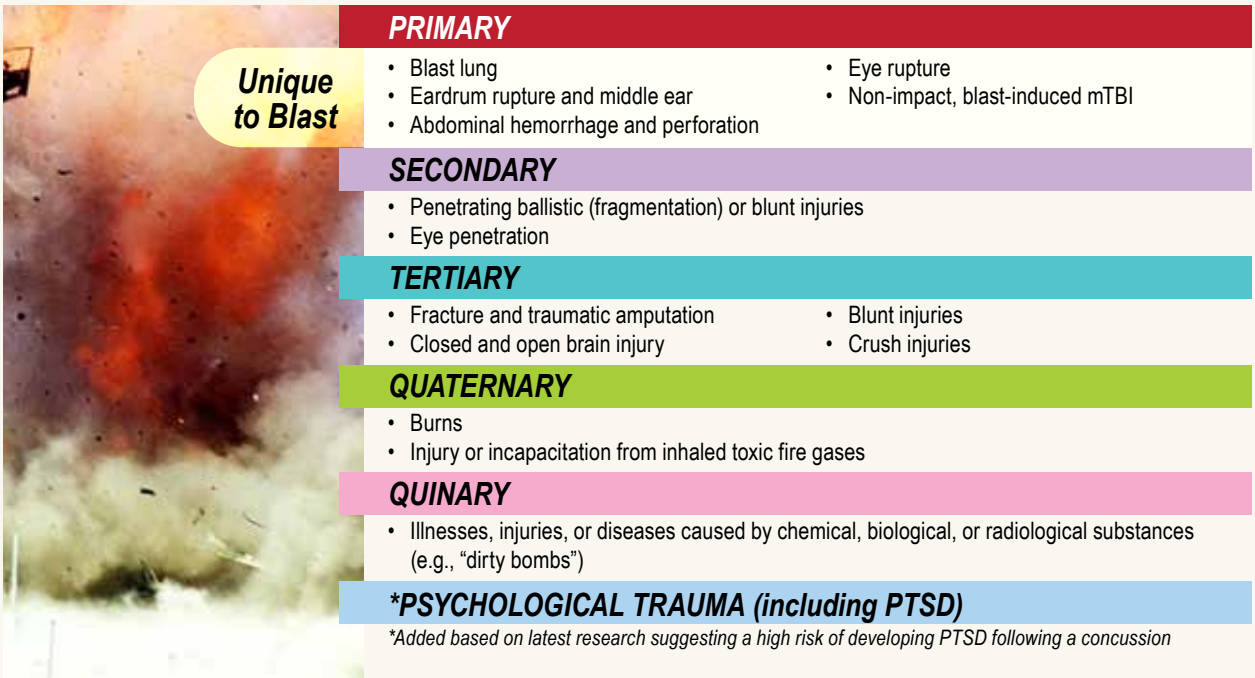


Figure 1-2. Types of Blast Injuries per DoDD 6025.21E

behind the pressure front propel fragments and debris against the body and cause blunt and penetrating injuries. The strong winds and pressure gradients also 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. These are known as tertiary blast injuries. Quaternary blast injuries are the result of other explosive products, such as heat, light, and toxic taxidromes 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-related injuries and will fully address traumatic brain injury (TBI) and post-traumatic stress disorder (PTSD) research. 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 new concept of "reset" for warfighters in redeployment, ensuring return-to-duty readiness (or healthy return to civilian life for citizen Soldiers). 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 1-3**).

Figure 1-3. Blast Injury Research Program Areas

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 vehicle crew 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 mitigate or prevent injuries.

Acute Treatment

Acute Treatment mitigates injury by providing acute 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 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.

Funding

Medical research within the DoD is funded 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 made by Congress. CSI funds are often directed by Congress to topics that relate to the DoD core programs, for example, TBI and orthopaedic 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**. These programs, funded through the Defense Health Program, are managed by the USAMRMC. Core funding programs of the DoD services and agencies are discussed as follows.

Service and Agency Programs

The Army, Navy, Air Force, and the Defense Advanced Research Projects Agency (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, military operational medicine (prevention and return to duty), and clinical and rehabilitative medicine. In fiscal year 2010 (FY10), the Office of the Assistant Secretary of Defense for Health Affairs (OASD[HA]) established a core research and development program to enhance the related medical research and development programs of the services and DARPA, accelerating the transition of medical technologies into products and knowledge into new standards of care. The current emphasis

Table 1-1. CSI Programs with Blast Injury-Related Research

CSI Program	Program Focus
Psychological Health and Traumatic Brain Injury (PH/TBI) Research Program	Focuses on research to promote a better standard of care for PH (including PTSD) and TBI in the areas of prevention, detection, diagnosis, treatment, and rehabilitation. Topics under this program are related to the physics of blast, rehabilitation and reintegration, neuroprotection and repair, treatment and clinical management, families and caregivers, and field epidemiology.
Peer Reviewed Orthopaedic Research Program	Supports military-relevant orthopaedic research. The program focuses on issues related to the treatment and recovery from soft tissue wounds and bone fractures, such as infection, compartment syndrome, non-union, heterotopic ossification, and temporary or permanent muscle function loss, among others.
Spinal Cord Injury Research Program	Supports research into regenerating/repairing damaged spinal cords and improving rehabilitation therapies. The program focuses on the care of these complex neurotraumatic wounds, including the prevention, alleviation, or care of medical complications from spinal cord injury, including adjustment to disability, autonomic dysreflexia, bladder and bowel dysfunction, pain, pressure ulcers, psychological disorders, sensory dysfunction or deficit, sexual dysfunction, and spasticity.
Vision Research Program	Targets the treatment of eye damage, visual deficits due to TBI, and diseases that, despite their different mechanisms and pathogenesis, all have a common end result: degeneration of the critical components of the eye and impairment or loss of vision. Research is focused on vision restoration and rehabilitation as well as visual system diagnostic/assessment capabilities and warfighter vision readiness and enhancement related to refractive surgery.
Peer Reviewed Medical Research Program	Addresses a wide range of fields of study with more than 80 topic areas since program inception. While many of the topics are not blast-related, recent solicitations included topics of composite tissue transplantation, nanomedicine for drug delivery science, post-traumatic 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/.

of that program is on the Secretary of Defense priorities of 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/agency programs is achieved through joint oversight/management committee structures, such as Joint Technology Coordinating Groups under the ASBREM Committee and Joint Program Committees under the Defense Health Program.

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 Armed Forces Institute of Regenerative Medicine (AFIRM), which is achieving major successes in advancing technologies for repairing traumatic injuries. Another is the Center for Neuroscience and Regenerative Medicine (http://www.usuhs.mil/cnrm) at the Uniformed Services University of the Health Sciences (USUHS).

Numerous DoD clinical 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 for Psychological Health and Traumatic Brain Injury (DCoE), the Traumatic Extremity Injuries and Amputation Center of Excellence (EACE), the Hearing Center of Excellence (HCE), the Pain Center of Excellence/Defense and Veterans Center for Integrative Pain Management, and the Vision Center of Excellence. Details on the EACE are depicted in **Table 1-3**.

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

Table 1-2. Armed Forces Institute of Regenerative Medicine

Armed Forces Institute of Regenerative Medicine http://www.afirm.mil/	
Established by the DoD in 2008 as a multi-institutional, interdisciplinary network of scientists with the mission of accelerating the development of new products and therapies to treat severe injuries suffered by U.S. service members. Research under the AFIRM is conducted through two independent research consortia working with the U.S. Army Institute of Surgical Research (USAISR). The AFIRM is focused on developing strategies to replace or regenerate human cells, tissues, or organs to restore or establish normal function. Funding is provided by USAMRMC, Office of Naval Research, U.S. Air Force Surgeon General, National Institutes of Health (NIH), Department of Veterans Affairs (VA), DoD(HA), and local public and private matching funding.	
AFIRM Program Areas	
Limb and Digit Salvage • Bone, soft tissue, and nerve repair/regeneration • Composite tissue injury repair • Composite tissue transplantation • Epimorphic regeneration **Craniofacial Reconstruction** • Regeneration of bone, soft tissue, and cartilage • Composite tissue allotransplantation **Scarless Wound Healing** • Control of wound environment and mechanics • Therapeutic delivery to wounds • Attenuation of wound inflammatory response • Scar mitigation	**Burn Repair** • Intravenous treatment of burn injury • Topical treatment of burn injury • Wound healing and scar prevention • Limit burn injury progression • Skin products/substitutes **Compartment Syndrome** • Cellular therapy of compartment syndrome • Biological scaffold-based treatment of compartment syndrome

Table 1-3. Traumatic Extremity Injuries and Amputation Center of Excellence

Traumatic Extremity Injuries and Amputation Center of Excellence
Jointly established by the DoD and VA in response to direction in the 2009 National Defense Authorization Act for the mitigation, treatment, and rehabilitation of traumatic extremity injuries and amputations.
The EACE is a "virtual center" bringing together efforts at DoD medical centers and VA Regional Amputation Centers. DoD Centers: • Center for the Intrepid, Brooke Army Medical Center, San Antonio, Texas • Military Advanced Training Center, Walter Reed National Military Medical Center, Bethesda, Maryland • Comprehensive Combat and Complex Casualty Care Center, Naval Medical Center, San Diego, California • Naval Medical Center, Portsmouth, Virginia VA Regional Amputation Centers serve as Level 1 flagship facilities: • Tampa, Florida • Richmond, Virginia • Bronx, New York • Minneapolis, Minnesota • Denver, Colorado • Seattle, Washington • Palo Alto, California
Purpose: • The EACE facilitates the continuous care and research related to traumatic extremity injuries and amputations across the DoD–VA multidisciplinary health care network. • The goal of the EACE is to improve capabilities for treating injured extremities, avoiding amputations, and preserving and restoring the function of injured extremities.
Initiatives of the EACE include: • Optimizing outcomes by analyzing data/research and providing guidance for developing clinical practice guidelines and best practices. • Defining the essential characteristics for a single, joint DoD/VA registry that can be accessed by both DoD and VA medical staff to facilitate case management, support longitudinal care, and assess clinical outcomes and research. • Working through DoD and VA agencies toward the implementation of a joint DoD/VA registry (if both funding and congressional guidance are provided to that effect). • Monitoring and analyzing published research for technical and clinical advances applicable to changes in best practices. • Engaging in a proactive strategic communications program, informing health care providers, health care beneficiaries, and the general public, about ongoing efforts and advances in the care of individuals with amputations and extremity trauma.

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. Key initiatives to learn from blast events (the Joint Trauma Analysis and Prevention of Injury in Combat [JTAPIC] program) to predict and monitor blast injury, to develop models of mild TBI (mTBI) (the DoD Brain Injury Computational Modeling Expert Panel), and to disseminate knowledge and enhance research collaboration (the State-of-the-Science Meeting Series) are presented. 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.

Chapter 2

DoD Blast Injury Research Program Coordinating Office

Mission: The Blast Injury Research PCO supports the DoD Executive Agent for blast injury research by coordinating DoD biomedical research programs aimed at preventing, mitigating, and treating blast-related injuries.

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 crew and personal protection system designs, as occupational exposure standards for blast-producing weapon systems, and as survivability assessment tools and metrics for combat vehicle crew survivability assessments.

In addition to DoD contributions to solving blast injury problems, 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 resides 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:

Identifying Blast Injury Knowledge Gaps and Prioritizing Research to Fill Gaps

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. 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 Joint Program Committees, 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 military operational medicine, combat casualty care, and clinical and rehabilitative medicine.
- **Integrating Integrated Product Teams (IIPTs).** The IIPTs were created to implement a teaming 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.

Overseeing the Joint Trauma Analysis and Prevention of Injury in Combat Program to Enhance Warfighter Survivability

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. in order to prevent and mitigate injuries. The PCO provides oversight for this program. See Chapter 3 for more information on the JTAPIC program.

Recommending Blast Injury Prevention Standards, Including Protective Equipment Performance Standards for the DoD

The PCO is collaborating with the Johns Hopkins University Applied Physics Laboratory (JHU/APL), a University Affiliated Research Center and DoD trusted agent, to develop an unbiased process for identifying and recommending Military Health System (MHS) Blast Injury Prevention Standards (BIPS). 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 vehicles, and effective protection against blast-related threats. See Chapter 4 for more on the BIPSR process.

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. For example, the PCO established the DoD Brain Injury Computational Modeling Expert Panel, which is developing a roadmap for a computational model of non-impact, blast-induced mTBI (see Chapter 5). This panel is composed of experts from the DoD, NIH, Departments of Energy and Transportation, academia, and industry. In addition to developing the roadmap, the panel will serve in an advisory role to the DoD program going forward. The State-of-the-Science Meeting Series is another vehicle that the PCO uses to leverage non-DoD expertise. Additionally, the JTAPIC program is taking advantage of data analysis and biomechanical modeling expertise from industry to support its mission to analyze data from battlefield exposure monitors, such as helmet sensors.

Serve as "One-Stop-Shopping" for 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:

- **Web Site.** The PCO has established a web site (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 Army leadership, other DoD organizations, industry, and academia. For example, the PCO coordinated a rapid response to a request from the Directors of the DoD Veterinary Services Activity and DoD Military Working Dog Veterinary Services for information on primary blast effects on dogs using historical data from an extensive blast bioeffects archive. Other examples 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.
- **Linking Researchers.** The PCO is able to use its network of research programs and knowledge of active blast research to link researchers from government, academia, and industry with common areas of interest.

Recent PCO Activities

Since its inception, the PCO has made significant progress in effectively coordinating DoD blast injury research. Examples of FY10–FY11 activities by the PCO include:

Identification of Blast Injury Research Knowledge Gaps

- **State-of-the-Science Meeting Series.** This meeting series brings together national and international SMEs to help identify knowledge gaps that will inform future research investments addressing specific blast injury research topics. Meetings have been held on blast-related tinnitus, blast dosimetry, and non-impact, blast-induced mTBI (see Chapter 6).
- **DoD Brain Injury Computational Modeling Expert Panel.** The PCO has assembled this diverse group of engineers, medical researchers, blast physicists, and clinicians from the DoD, other federal agencies, academia, and industry to explore the use of computational modeling to answer questions relating to the existence and mechanisms of non-impact, blast-induced mTBI. Through a series of meetings this panel has explored the knowledge gaps related to developing a computational model of mTBI and is developing a roadmap for future research to close these gaps. See Chapter 5 for information on the computational modeling effort.

Strengthened and Expanded Collaborations Between the Medical Research Community and Protection Equipment Developers

The medical research community has always played a critically important role in the development of individual and vehicle crew 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:

- Serves as the medical lead for the Vice Chief of Staff of the Army's (VCSA's) helmet-mounted sensor system (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.
- Served as the lead for the medical research component of the Warrior Injury Assessment Manikin (WIAMan) program, which is developing a warrior representative anthropomorphic test device 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 under-body blast (UBB) threats.
- Participates on program planning and review panels to identify blast-related knowledge gaps and helps set research program strategies. For example, the PCO helped to shape and focus the Combating Terrorism Technology Support Office (CTTSO)/Technical Support Working Group (TSWG) blast injury research FY11 Broad Agency Announcement by serving as a voting member on the TSWG Human Lethality IIPT and chairing the Blast Effects and Mitigation Subgroup. This subgroup identified blast-related research gaps that led to topics for the Broad Agency Announcement on blast injury models for massive projectiles and whole-body displacement effects.

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. Efforts are ongoing with France, Germany, Israel, the United Kingdom, and the North Atlantic Treaty Organization (NATO).

Significant international program coordination events included:

- Accompanied the ASA(ALT) delegation to QinetiQ Group PLC, Farnborough, United Kingdom, for a Vehicle Technology Integration Demonstrator demonstration and to the United Kingdom's Infantry Center at Warminster for briefings with the Infantry Trials and Development Unit. The demonstrations included the Jackal, Integrated Soldier Capability, and electro-optic protective measures. Identified were areas for collaboration, such as comparing methodologies and analyses of Operation Enduring Freedom (OEF) injuries.
- Briefed Sir Leszek Borysiewicz, Chief Executive of the Medical Research Council, United Kingdom. Subjects presented included overviews of DoD Blast Injury Research Program initiatives and the JTAPIC program. Information exchanges such as this serve to identify capabilities and opportunities for partnership.
- Briefed the United Kingdom Surgeon General, VADM Raffaeli, on "Blast Injury Prevention Initiatives." The presentation outlined the stand-up of the Blast Injury Research PCO, the JTAPIC program, the State-of-the-Science Meeting Series, and the USAMRMC Blast Lung Injury Dosimeter.
- Briefed the Director General of the United Kingdom's Army Medical Services on the

DoD Blast Injury Research PCO, including the background of the PCO as well as key program components such as JTAPIC program highlights and the State-of-the-Science Meeting Series. Several questions were also fielded concerning the high incidence of hearing loss among warfighters.

- Participated in the second meeting of the NATO task group on "Injury Assessment Methods for Vehicle Active and Passive Protection Systems" (HFM-198/RTG 2010-2012). This task group is responsible for developing technical recommendations for STANAG 4569 (Protection Levels for Occupants of Logistics and Light Armored Vehicles) and STANAG 4686 (Qualification of Active Protection Systems). Of particular concern are accelerative injuries from UBB, specifically, gaps in injury criteria and assessment methods for predicting soft tissue injuries and injury risks to "out-of-position" vehicle occupants. Positioning in real-life combat operations often does not reflect the standard position (properly seated and restrained) upon which current generation of test dummies is based; therefore, injury risk assessments may be inaccurate. Issues raised at this meeting are being used in the development of the research plan for the WIAMan effort.
- Briefed the JTAPIC program at the Five Power (5P) Senior National Representatives Army (SNR[A]) mini conference. The 5P SNR(A), consisting of representatives from the United States, United Kingdom, Germany, France, and Italy, was formed to look at things that may be useful to NATO. German, French, and Italian representatives were specifically interested in the JTAPIC program. An action item was taken for Germany and the JTAPIC program to develop a joint brief to present to NATO. As a result, Germany and the United States are cooperating on improving injury and vehicle incident data collection processes and analysis to support survivability and vulnerability assessment by materiel developers.

Significant international science events included:

- Presented and discussed DoD Blast Injury Research Program initiatives at the "Blast Injuries: Advances in Understanding, Assessment, and Treatment" symposium organized during the 8th World Congress on Brain Injury.
- Co-chaired a scientific session on "Computational Models of Non-Impact, Blast-Induced Traumatic Brain Injury" at the 7th Annual World Congress of International Brain Mapping and Intraoperative Surgical Planning Society. This topic represents a recognized knowledge gap in the DoD Blast Injury Research Program, and the PCO has an ongoing effort to develop a research roadmap to resolve the gap.
- Provided a forum at USAMRMC for Dr. Chaim Pick, Chairman, Department of Anatomy, Tel Aviv University, Sackler School of Medicine, Israel to present his research entitled, "Blast Brain Injury: A Combat Zone-Like Mouse Model. From the Experimental Lab to the War Against Terror and Back to the Lab." Dr. Pick's work consists of the development of a mouse model for blast injury that includes realistic blast exposures similar to the types of exposures observed in terrorist attacks and in the combat environment.
- Co-chaired a program committee of the NATO Research and Technology Organization's Human Factors and Medicine (HFM) Panel. The committee organized the HFM-207 symposium on "A Survey of Blast Injury Across the Full Landscape of Military Science" (October 3–5, 2011) to increase the understanding of blast injuries and identify knowledge gaps requiring additional research to improve prevention, mitigation, and treatment strategies. This symposium was open to Partnership for Peace, Mediterranean Dialogue Initiative, and Contact Nations.

PCO in the News

- **Joint Trauma Analysis and Prevention of Injury in Combat Program**, *Stand-To!*, December 17, 2009, described the JTAPIC program and what the Army has done with the actionable information provided by the JTAPIC program. The article is available at http://www.army.mil/standto/archive/2009/12/17/.
- **Behind Armor Blunt Trauma Assessment Program – Using Computational Modeling to Develop a Biomedically Based Method for Assessing Body Armor Performance**, *Army Modeling and Simulation Office News*, Volume 4, December 31, 2009. This article is available at http://www.ms.army.mil/library/newsletters.html.
- **Analysis Program Focuses on Preventing Combat Injuries**, *Military Health System News*, March 2, 2010, highlighted the JTAPIC program partnership and its contribution to warfighter injury mitigation and survivability. The article is available at http://www.health.mil/News_And_Multimedia/News/detail/10-03-02/Analysis_Program_Focuses_on_Preventing_Combat_Injuries.aspx.
- **A Closer Look at the DoD Blast Injury Research Program Coordinating Office**, *Military Medical and Veterans Affairs Forum*, December 2010. This article highlights the goals, key issues tackled, and accomplishments of the Blast Injury Research Program. The article is available at http://www.military-medical-veterans-affairs-forum.com/mmt-home/290-mmt-2010-volume-14-issue-8-december/3705-organizational-profile.html.
- **Research Examines Blast Impact on Human Brain**, *Armed Forces Press* Service, April 12, 2011. This article by Donna Miles features the DoD Blast Injury Research Program and the important work being done by the DoD Brain Injury Computational Modeling Expert Panel (see Chapter 5 for more information on this effort). The article is available at http://www.defense.gov/News/NewsArticle.aspx?ID=63523.
- **Army Device Will Gauge Blast Hits on Soldiers**, *USA Today/Military*, July 19, 2011. This article by Gregg Zoroya focuses on the DoD's blast sensor initiatives. The article is available at http://usatoday30.usatoday.com/news/military/2011-07-18-army-device-measures-brain-injuries_n.htm.

Addressing Under-Body Blast

- **Under-Body Blast "Processes and Standards" Modeling and Simulation Working Group.** The PCO participated in a working group that reviewed a number of DoD and service policy and guidance documents. The working group recommended using the Survivability/Vulnerability Information Analysis Center as the repository for DoD UBB models and data. Furthermore, it recommended that the DoD consider using a risk-based model accreditation methodology. To streamline verification, validation, and accreditation (VV&A) efforts, the working group recommended that VV&A plans be prepared simultaneously during the VV&A process. It was noted that VV&A processes were similar, but there was variance among the modeling and simulation approaches.
- **Under-Body Blast Industry Day.** The PCO, in coordination with the RAND Arroyo Center, hosted an industry day to inform industry, academic, and governmental entities; inform medical research planning; and identify existing technologies, relevant capabilities, and optimum approaches that would enhance the live-fire

test and evaluation (LFT&E) community's ability to accurately assess ground combat vehicle occupant survivability in UBB events and enable the development and testing of improved occupant protection systems.

- **Planning for USAMRMC's Under-Body Blast Research Program.** In coordination with the OASD(HA), planning was begun for the Under-Body Blast Research Program (UBBRP). The UBBRP is a medical research program intended to develop enhanced capabilities for predicting injuries caused by UBB in ground combat vehicles. This research program is responsive to an issue paper from the Director, Operational Test and Evaluation (DOT&E), which cited significant shortfalls in injury prediction capabilities needed to support the congressionally directed LFT&E program. The UBBRP was designed to leverage expertise from the broad medical research community that resides within the DoD, other federal agencies, academia, industry, and international organizations. The UBBRP plans were ultimately translated into the WIAMan program.
- **Deep Dive Working Group on Modeling and Simulation Capabilities.** The PCO played a major role as a member of this working group, which was established in response to the Secretary of Defense memorandum on the Mine-Resistant, Ambush-Protected Vehicle operational test and evaluation report that directed a review of developmental modeling and simulation tools for blast testing of vehicles. The intent was to develop a recommendation to the Secretary of Defense (through Director, Defense Research and Engineering) of science and technology initiatives required to provide a robust modeling and simulation capability that is verified, validated, and accredited to the holistic acquisition community. The expected product was a documented modeling and simulation assessment with gaps and options for filling the gaps. The group determined that prescribing a single model was not the best path forward and decided to focus on requirements in the context of the underlying group premise of using high-performance computing tools.

Informing Protective Equipment Development

- **Soldier Ballistic and Blast Protection Science and Technology Investment Strategy Planning.** The PCO participated in an initiative led by the Natick Soldier Research, Development, and Engineering Center (NSRDEC) to identify the needs covering the broad spectrum of future Soldier protection desired capabilities. The mission of the group is to develop the Army's Science and Technology Investment Strategy for Individual Dismounted Soldier Ballistic and Blast Protection. The stakeholders identified included: NSRDEC, Army Research Laboratory (ARL), USAMRMC, the JTAPIC program, Program Executive Office (PEO) Soldier, Training and Doctrine Command (TRADOC), and National Ground Intelligence Center (NGIC).
- **Occupant Centric Survivability Project.** The PCO participated in the Occupant Centric Survivability project kickoff meeting hosted by the U.S. Army Tank Automotive Research, Development, and Engineering Center (TARDEC). The objective of the project is to provide increased protection to the warfighter through the standardization of an "occupant centric" approach to vehicle safety design by utilizing the modeling and simulation tools that already exist to reduce casualties related to blast/crash events. In addition, the project plans to foster new interagency relationships between the vehicle development, test and evaluation, and medical communities, both military and commercial.
- **PEO Soldier's Head Protection Conference.** During plenary sessions, the PCO addressed the conference on the findings of the PCO's 2009 State-of-the-Science Meeting on "Non-Impact, Blast-Induced mTBI" and the efforts of the PCO's DoD Brain Injury Computational Modeling Expert Panel to close the gaps in the current understanding of the existence and mechanisms of this injury. Key points included: (1) the current state of the science on this topic does not support the modification of current head protection systems or the development of new ones to protect against this particular

injury, (2) the current DoD blast injury research portfolio contains many projects that are focusing on this topic, and (3) the DoD Brain Injury Computational Modeling Expert Panel of respected scientists and engineers from the DoD, other federal agencies, academia, and industry is working diligently to close key knowledge gaps relating to this topic.

- **Eye Protection/Transparent Armor Technology/ Capability Roadmapping Workshop.** At this NSRDEC-hosted workshop, the PCO briefed injury trends and a facial injury study done by the Naval Health Research Center's (NHRC's) Department of Medical Modeling and Simulations. The objective of the meeting was to define technology goals for individual eye protection equipment/transparent armor from 2012–2025. The meeting resulted in recommendations for short- and long-term goals, including improving ballistic protection of eyewear; understanding the characteristics and effects, and potential injury mechanisms, of BOP transmitted to the eyes and eyewear; and integrating eyewear into the combat helmet.
- **Test Resource Management Center.** The PCO hosted a meeting with the Program Manager (PM), Test Resource Management Center (TRMC) to understand the TRMC mission and explore future collaborative efforts. The TRMC is responsible for overseeing the DoD's test and evaluation infrastructure. The discussion focused on BIPS, a possible partnership with the JTAPIC program, gaps in the testing community, and inclusion of medical technologies in the TRMC strategic plan starting in 2012. Meeting attendees included representatives from the OSD DOT&E and the U.S. Army Aberdeen Test Center, U.S. Army Evaluation Center.

Informing Body Armor Test Methods

- **Body Armor Performance Testing Meeting.** The PCO briefed future body armor performance testing methods at a meeting hosted by the OSD DOT&E at the Aberdeen Test Center. The OSD DOT&E's objective for this meeting was to gain consistency in the clay-based body armor performance testing method currently used by the DoD. The DoD uses the clay-based body armor performance test developed by the National Institute of Justice. The PCO's presentation focused on the need to replace the institute's test with a biomedically valid body armor performance testing method based on a validated correlation with human blunt trauma injuries. The PCO co-chaired a working group on future body armor performance testing methods with the ARL Survivability/Lethality Analysis Directorate (SLAD).
- **High-Strength Fiber and Body Armor Research Needs Meeting.** The PCO participated in this meeting, which was hosted by the National Institute of Standards and Technology. Topics discussed included the life-cycle testing of body armor and improved performance testing methods. Collaborations established during this meeting will help advance the state of the science in body armor development and performance testing and may lead to an improved performance test for civilian and military application.
- **Behind Armor Thoracic Blunt Trauma Working Group.** The PCO co-chaired, along with the ARL/SLAD, the first meeting of this working group. The OSD DOT&E established this working group to explore potential replacements for the current clay-based body armor performance testing methodology. The PCO presented its BIPSR process and suggested that this process could be used to identify and evaluate candidate body armor performance testing methodologies. The working group meeting concluded that there is a need for a new body armor performance testing methodology and suggested the BIPSR process as a possible mechanism for identifying and assessing candidate testing methodologies.

- **Clay Development Synchronization Meeting.** This meeting was hosted by the OSD DOT&E to identify and prioritize projects intended to resolve deficiencies with the DoD's current clay-based body armor performance testing methodology and to identify a biomedically relevant alternative to the clay test. The PCO presented data on the USAMRMC's research that led to a body armor ballistic testing device known as the Anthropomorphic Test Module coupled with a computational model that predicts the probability and severity of specific human blunt trauma injuries. USAMRMC is working to develop a simplified version of the device and a blunt trauma injury model that may be acceptable to the testing community as an alternative to the clay test.

Advancing Science and Medicine

- **State-of-the-Science Meeting Series.** See Chapter 6 for more information on the State-of-the-Science Meeting Series.
- **First Symposium on Traumatic Brain Injury.** The PCO participated in the symposium organized by the Center for Energetic Concepts Development Center, University of Maryland. Participants from the Indian Head Division of Naval Surface Warfare Center, University of Maryland School of Medicine, and the Department of Mechanical Engineering presented their ongoing research and discussed proposed research plans related to blast-induced TBI. Topics included targets of neuroprotection, magnetic resonance imaging (MRI) markers, the MEMS (MicroElectroMechanical Systems) sensor suite for excessive load detection, computational models for blast loading of the brain, the use of explosives to investigate brain injury mechanisms, and blast wave interactions with soft tissue matter. The PCO plans to actively participate and monitor the progress of the group, especially the project exploring the feasibility of developing a blast dosimeter using MEMS technology.
- **Office of Naval Research Program Review of Basic Research Challenge – Polymer Application for Prevention of Traumatic Brain Injury.** The PCO participated in the Office of Naval Research's program review. The program is trying to understand how energy dissipates when polymeric materials are subjected to high-rate loadings as found in multifrequency blast waves. Program projects aim at understanding the relationship between polymer structure/morphology and blast energy dissipation mechanisms, designing of new polymers with optimal properties for shock loading, and understanding the mechanics of the polymer/helmet system in diverting blast-induced shock waves away from the head.
- **Blast Injury Research Meeting, Center for Neuroscience and Regenerative Medicine, USUHS.** The PCO presented on the first State-of-the-Science meeting regarding "Non-Impact, Blast-Induced mTBI." The Defense Medical and Environmental Research Institute, DSO National Laboratories, Singapore, gave a presentation on its DARPA-sponsored research on blast-induced TBI. Its research, which is a component of the DARPA PREVENT (Preventing Violent Explosive Neurological Trauma) program, is studying the physical and cognitive effects of blast exposures on nonhuman primates. One of the significant findings that has emerged from this work is that the measured levels of electromagnetic pulse generated by the uncased explosive charges used to produce the blast exposures appear to be insignificant. The electromagnetic pulse is one of many possible mechanisms that may be responsible for causing non-impact, blast-induced mTBI. The next phase of research is focusing on the development of a nonhuman primate finite element (FE) model.
- **DoD Hearing Center of Excellence Concept of Operations Planning.** The PCO participated in identifying achievable metrics/goals in the following HCE mission objectives:

Prevention and Surveillance; Clinical Care, Rehabilitation, and Restoration; Informatics/ Information Management; Global Outreach; and Research. The PCO's representative was also the Air Force SME for the DoD HCE. He developed short- and long-term strategies for: (1) restoration of hearing loss as it relates to current treatment and rehabilitative device-dependent outcomes, (2) methods of repair and healing of significant blast injuries focusing on the desired ability to rehabilitate and retain members in functional military roles, and (3) staffing levels for certified vestibular therapists within the MHS and curriculum required to obtain certification in the treatment of TBI patients.

- **Other Scientific Meetings.** Additional scientific meetings in which the PCO was involved are reported previously under the International Cooperation and Collaborative Activities section.

Linking with Other Federal Agencies and Industry

- **Blast Community Forum.** This meeting was sponsored by the Physical Security Subgroup of the CTTSO/TSWG. The Bureau of Alcohol, Tobacco, Firearms, and Explosives; Department of Energy; and the DoD co-chair the Physical Security Subgroup. Its focus is on rapid physical security solutions for federal organizations that have a countering terrorism mission. The purpose of this subgroup meeting was to familiarize the physical security community with blast-related activities, including ongoing research efforts. This forum provided an opportunity for the PCO to inform participants from a variety of federal agencies on key blast injury research gaps that helped shape the TSWG's 2011 research investments.
- **Toyota Technical Center, Toyota Motor Engineering and Manufacturing North America.** The PCO met with Toyota representatives to explore common interests in the development of tissue/organ injury criteria. Over the past several years, Toyota has invested in research and development to understand the differences in structure and material properties of the human organs to simulate the impact behavior of organ parts and their injuries. Toyota's research efforts have resulted in a next-generation human FE model "Total Human Model for Safety" capable of organ injury prediction. The discussion centered on the feasibility of collaborative efforts regarding basic technologies and its application to understanding UBB injuries.

Establishing Key Agreements

- **Sharing Injury Models and Research Between Army and Navy.** The PCO coordinated a Memorandum of Understanding to establish a collaborative relationship between USAMRMC and the Office of Naval Research for the purpose of transitioning USAMRMC-developed injury and performance prediction models, to include the INJURY (software for making an assessment of lung injury from exposure to BOP) and TGAS (Toxic Gas Assessment Software) models, into Navy applications. The Navy will benefit from leveraging the existing Army-developed technologies to help accelerate meeting its congressionally mandated LFT&E requirements and to verify adequate manning and cross-training of personnel for the determination of medical response requirements. The objective of the Navy's Human Injury and Treatment (HIT) program is to produce a computer-modeling tool for predicting human injury, incapacitation, and medical response requirements associated with blast attacks in shipboard environments. The Navy has agreed to transition the results of its HIT science and technology efforts to the extent they can be used by the U.S. Army. This will include providing USAMRMC with documentation of a fully developed Military Combat Injury Scale scoring system; research data, software, specifications, and documentation related to expansion of the capabilities for whole-body displacement, blunt trauma, and smoke inhalation models; and the results of verification tests to determine whether models, as implemented under the HIT program, generate the same results as the stand-alone versions of the Army-developed models.

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 to assist in fulfilling portions of the Secretary of the Army's EA responsibilities under DoDD 6025.21E.

The JTAPIC program mission is to facilitate the joint collection, integration, and analysis of data and information to improve our understanding of vulnerabilities to threats and enable the development of improved TTPs, requirements, materiel solutions, models, etc. in order to prevent and mitigate injuries.

Prior to 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 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 articles were returned, the analysis was performed without the benefit of operational context or injuries to the warfighter. Operational context basically means understanding what happened to the warfighter and what he or she was doing when the injury occurred. 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, there was no formal process for providing medical injury data associated with combat operations to nonmedical users, such as combatant commanders, 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: to collect, integrate, and analyze injury, materiel performance, and operational data to improve the understanding of vulnerabilities to threats and enable the development of improved TTPs and materiel solutions that will prevent and/or mitigate traumatic injuries.

Since its inception, the JTAPIC 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, TRADOC, and other senior decision makers. The program has received personal endorsements from the VCSA, Secretary of the Army, OSD DOT&E, the Surgeon General of the Army, PM Stryker, PM Mine Resistant Ambush Protected Vehicles, and U.S. Army Materiel Command Surgeon.

The JTAPIC program was recognized by the National Museum of Civil War Medicine and awarded the annual Major Jonathan Letterman Award for Medical Excellence to recognize its

contributions to the advancement of medical processes and improved patient outcomes and quality of life. The JTAPIC program by definition is a relationship of multiple agencies coming together to prevent and mitigate traumatic injuries in combat.

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 combat casualty care 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. JTAPIC Program Partners

JTAPIC Program Partners	
Marine Corps Systems Command	U.S. Army Infantry Center and School
Naval Health Research Center	U.S. Army Institute of Surgical Research
Armed Forces Medical Examiner System	U.S. Army National Ground Intelligence Center
Maneuver Center of Excellence, Dismounted Incident Analysis Team	U.S. Army Research Laboratory, Survivability/Lethality Analysis Directorate
Marine Corps Intelligence Activity	U.S. Army PEO Soldier, Project Manager Soldier Equipment
Program Manager Infantry Combat Equipment	U.S. Army Aeromedical Research Laboratory

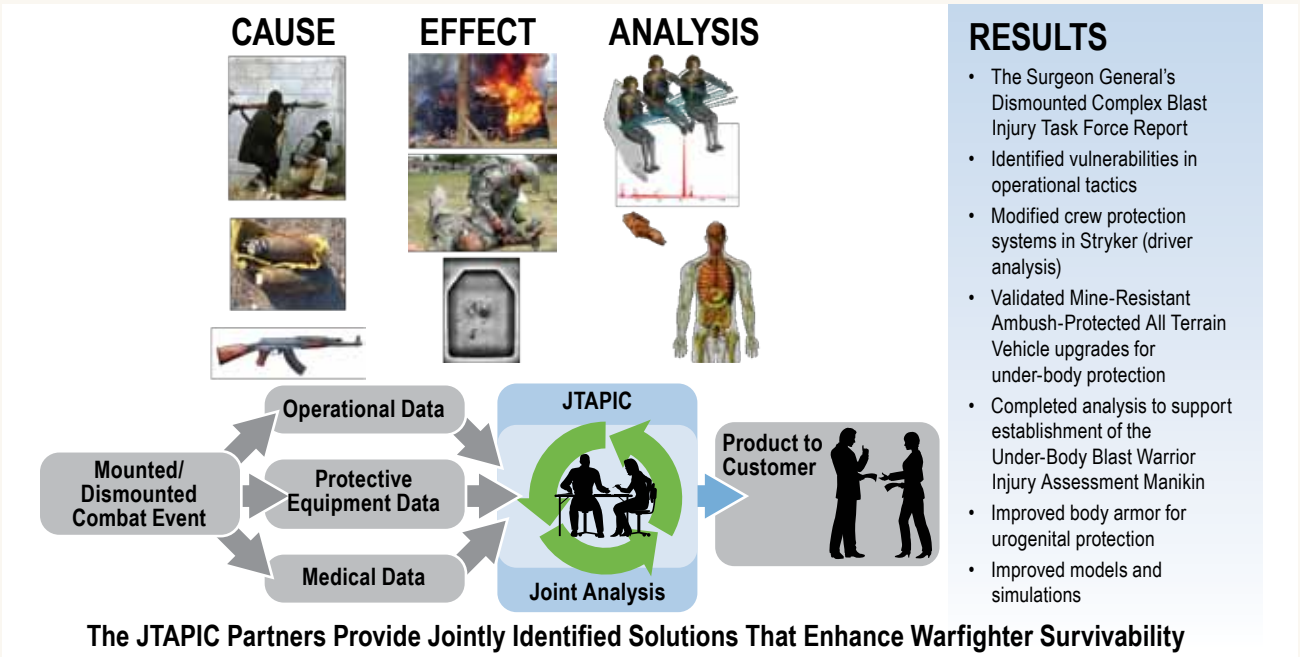


Figure 3-1. JTAPIC Analysis Process

Program Structure

Figure 3-2 depicts the structure of the JTAPIC PMO. Key components of the PMO are:

Mounted Analysis Project Area

The mounted analysis project area analyzes events where mounted warfighters are injured 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

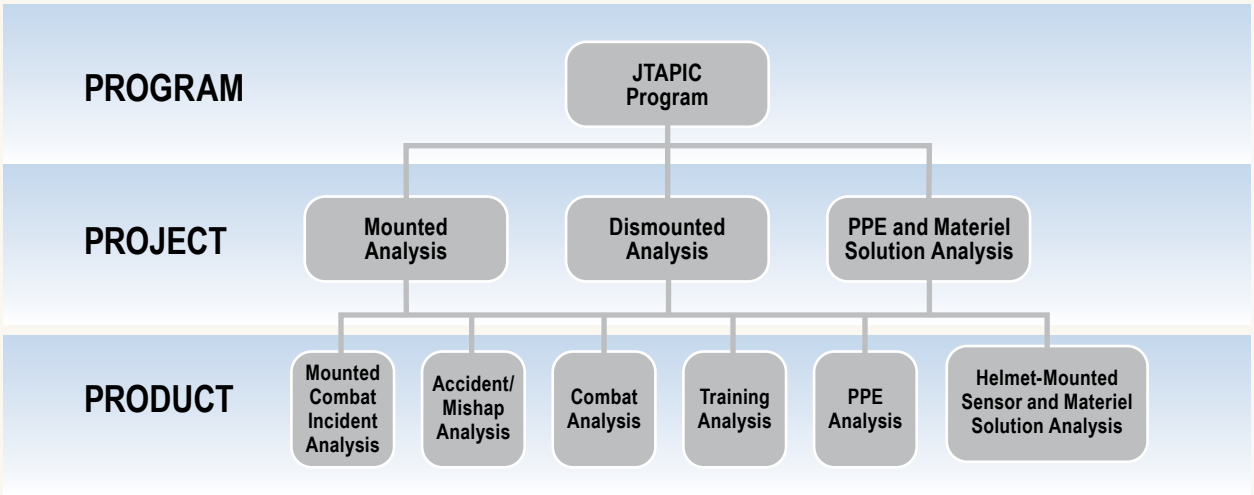


Figure 3-2. JTAPIC Program Structure

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 where dismounted warfighters are injured 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 the TRADOC to influence protective equipment design and TTPs, respectively. During peacetime, the dismounted training analysis 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.

Personal Protective Equipment and Materiel Solution Analysis

The JTAPIC program collects KIA and WIA PPE that has been damaged in some way 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 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 used incident, injury, and virtual autopsy data to identify potential vulnerabilities in operational procedures and rapidly conveyed those 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 has engaged with the DCoE to support the DCoE in its role in monitoring concussion/mTBI events (**Table 3-2**). Another key benefit of the JTAPIC program is its ability to provide coordinated responses to inquires from across the DoD.

Table 3-2. JTAPIC Partnering with the DCoE

JTAPIC Partnering with the DCoE
Directive Type Memorandum 09-033, Policy Guidance for Management of Concussion/Mild Traumatic Brain Injury in the Deployed Setting • Issues guidelines for blast exposures requiring mandatory medical evaluation for mTBI • Directs the DCoE to conduct analyses of event-triggered mTBI data reported by the services and combatant commands and to develop event-specific monitoring summaries
Under DoDD 6025.21E, the JTAPIC program has existing event-related reporting and analyses processes
The DCoE can leverage JTAPIC to avoid duplicative processes
The JTAPIC program will consolidate the mandatory event data and add a medical record review and assessment of the possible diagnosis of concussion based on the event documentation in the medical record
The JTAPIC program will provide monthly summaries to assist the DCoE in meeting the Directive Type Memorandum responsibilities

Key Initiatives

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

International Outreach

As a part of the Technical Cooperation Program AG-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 performance and injury patterns in the context of current and future operations. The AG-3 encompasses representatives from the United States, Canada, United Kingdom, and Australia. Each participating nation has established (or is establishing) its own respective JTAPIC-like program.

Additionally, the JTAPIC program participates as part of the 5P SNR(A). The 5P SNR(A) consists of representatives from the United States, United Kingdom, Germany, France, and Italy. 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 done, they then present to NATO, and the appropriate NATO body can then vote to accept the 5P work.

Lean Six Sigma Initiative

The JTAPIC PMO continues to work with JTAPIC program partners to streamline the analyses processes and the flow of information from the partners to customers through a Lean Six Sigma Initiative. The objective is to use the existing framework of the JTAPIC program partnership to coordinate joint analyses of data by the partners, including analyses of medical data by the medical partners, and to enhance the flow of information among partners from the Request for

Information (RFI) input to a coordinated analysis output. All partners have specific data sources that they analyze and interpret using their own unique knowledge and skills. The Lean Six Sigma effort is focused on improving the efficiency and effectiveness of the JTAPIC process in a way that places emphasis on warfighter needs.

By improving the speed and quality of the JTAPIC partner sharing and integration products, the following improvements are anticipated: (1) reduction of customer-generated RFIs per number of total incidents; (2) increased percentage of RFIs that JTAPIC program partners can answer with available integrated partner-generated data; (3) reduced overall process cycle time to produce partner-generated integrated datasets; and (4) reduced process cycle time of RFI turnaround.

Helmet-Mounted Sensor System

The PEO Soldier-led Generation II Helmet-Mounted Sensor System (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 Advanced Combat Helmet, will record blast pressure, and linear and rotational acceleration. The JTAPIC program team will analyze Gen II HMSS data to determine if Gen II HMSS acceleration data can be used to confidently predict head injuries.

Under the prior Gen I project, the JTAPIC program, in partnership with the PM Soldier Protective Equipment (PM SPE) and PM Infantry Combat Equipment (PM ICE), led an HMSS data analysis project that contributed to the improvements incorporated into the Gen II device and effort.

See Chapter 4 for more on efforts to develop monitors of blast exposure and the HMSS effort.

Personal Protective Equipment Urogenital Protection

The JTAPIC program partnership has conducted an analysis of urogenital injuries for relevant incidents. The overwhelming majority of casualties with urogenital injuries had multiple injuries to other areas of the body and many of them were significant (**Figure 3-3**). The analysis states that 56% of the casualties who received urogenital injuries received penetrating wounds to the genital organs (i.e., scrotum, testes, and penis). Additionally, it also states that 20% of casualties who received urogenital injuries had catastrophic pelvis injury, and 40% are accompanied by severe or critical injuries to the extremities. No undergarment is capable of countering these wounds. The information indicates that 40% of pelvic and groin injuries may be potentially mitigated through additional protection.

Efforts in providing armor for this area of the body have yielded the development of two levels of protection for the pelvic region. The purpose of a pelvic protection system is to mitigate femoral artery and urogenital injuries sustained by dismounted Soldiers in the vicinity of IED blasts. The Tier I Protective Under Garment (PUG)—part of the pelvic protection system—is a developmental item that will provide protection against ground-based IED threats. The PUG is worn next to the skin and provides protection of the pelvis, femoral arteries, and lower abdominal organs in a blast or fragmentation event. The PUG will also reduce the penetration of dirt and fine debris into a wound area to help prevent

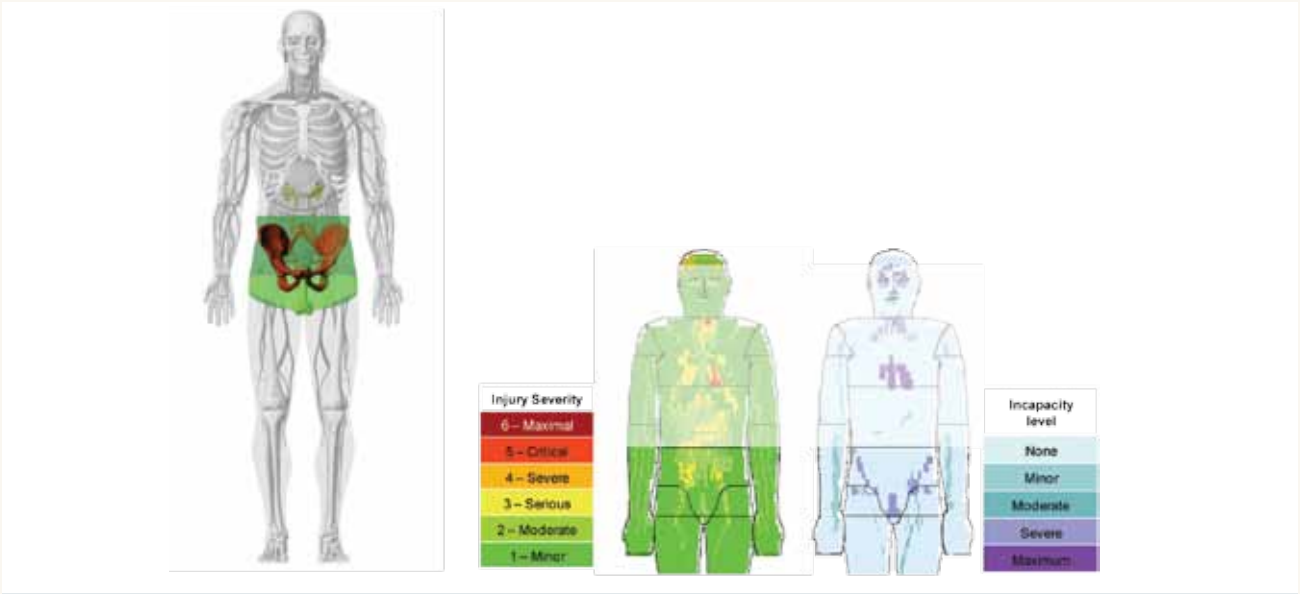


Figure 3-3. Personal Protective Equipment Urogenital Protection

infections. The Tier II Protective Outer Garment (POG)—part of the pelvic protection system—is a developmental item that will provide protection against ground-based IED threats. 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 to help prevent infections (**Figure 3-4**). The U.S. Marine Corps Systems Command has also acquired and fielded Tier I and Tier II (PUG and POG) systems beginning October 2011.

POG PUG

Figure 3-4. Examples of POG and PUG

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.

The first sessions of wounded warrior interviews were conducted at the Walter Reed Army Medical Center Warrior Transition Unit by the JTAPIC Mounted and Dismounted Project Area in the first quarter of FY11. The type of information provided by the wounded warriors is not routinely reported from theater (e.g., number and location of vehicle crew members, warfighters who were returned to duty status, etc.). The JTAPIC program continues to coordinate with Warrior Transition Units at all levels throughout the continental United States to conduct interviews with warriors in transition.

Battlefield Vehicle Forensics Team

The Battlefield Vehicle Forensics Teams (BVFTs) are 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 NGIC is the JTAPIC program partner charged with the mission of investigating all attacks on U.S. vehicles worldwide to establish what weapon was 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 to accomplish this mission. One of the most important of these is 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. Their mission is to conduct detailed, hands-on collection of data from battle-damaged vehicles as close to the time and location of the incident as possible. The BVFTs are a unique collection means and often provide the key to understanding incidents of high interest.

Responding to Requests for Information

To date, the JTAPIC program has processed approximately 380 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:

- PM SPE requested that the JTAPIC program address the issue of ballistic undergarments in February 2011. There have been several RFIs on this same issue to include the Urgent Universal Needs Statements received from the Marine Corps in January 2011. PM SPE market analysis indicates there are a variety of similar systems available in the commercial market place that merit further study; while this is a novel concept, there are no data to support the assumption that this product reduces the number or severity of injuries in combat. The JTAPIC program provided a medical data analysis showing that the vast majority of reported injuries greatly exceeds the capability of this garment. This analysis addressed quantification of casualties receiving penetrating pelvic injuries, characterization of the types and severities of urogenital injuries witnessed versus potential mitigation provided by ballistic undergarments, and determination of a need for ballistic pelvic protection based on injury severity and long-term effects of urogenital injuries.

- JTAPIC's Dismounted Analysis Project Area responded to an RFI from theater for a survey of potential materiel solutions suitable for gunner protection from blunt trauma. An analysis of facial injury type and severity in the context of personnel location (i.e., mounted/dismounted, gunner, driver, and passenger) was conducted to inform decisions on a potential face shield or other solutions. The study concluded (1) the most frequent facial injuries overall were ear injuries to the tympanic membrane; (2) the most frequent facial injuries that were rated as mild were fractures to facial bones, particularly the malar/maxillary bones; and (3) 25% of personnel with facial injuries also sustained an eye injury.
- In February 2011, an analysis of operational scenarios (including specific IED types) resulting in amputations was presented to the Joint IED Defeat Organization Operations Research Systems Analysis Division. The analysis looked at geographic location, threats, and other factors that may have contributed to the amputation trends. Medical data provided in an operational context are valuable in verifying and validating priorities identified by the division.
- The Operations Research Systems Analysis Division of the U.S. Army Maneuver CoE had requested specific information on the most common IED targeting dismounted troops and the level of protection required to mitigate that threat. The analysis included the most common and effective IED employed against dismounted troops and considered initiation method, emplacement technique, explosive weight, explosive composition, and enhancements (such as fragmentation, added fuel, etc). Also included in the analysis was the most typical fragmentation impacting dismounted troops from such blasts (i.e., composition, mass, velocity) and the materiels currently existing capable of defeating the blast.
- The JTAPIC program completed a gunshot wound analysis that included medical data from NHRC and the Armed Forces Medical Examiner System (AFMES) on WIAs and KIAs who received gunshot wounds in OEF from January 1, 2009 through December 31, 2011. The analysis includes date of event and event number, Abbreviated Injury Scale (AIS)-coded injury data, an injury description, entrance/exit wound locations if available, and any information on recovered ballistic fragment evidence. All recovered ballistic fragment evidence from the AFMES for KIAs during this time period was analyzed and identified. PEO Soldier evaluated the PPE involved in each event when available.
- In support of the Soldier Requirements Division U.S. Army Maneuver CoE brief to Headquarters, Department of the Army on improvements made to Soldier protective equipment and the effects those improvements have had on Soldier survivability and injury mitigation, the JTAPIC Dismounted Analysis Project Area provided a report with accompanying briefing slides that graphically portrayed distribution, frequency, mechanism of injury, and severity

of combat injuries to Soldiers broken down by body regions (i.e., head, neck, face, thorax, abdomen, pelvic, upper extremities, and lower extremities). This information and analysis will be used to determine if changes/improvements in Soldier protective equipment have resulted in improvements to Soldier survivability and/or mitigation of injury severity.

- The Mounted Analysis Project Area works closely with many organizations from the LFT&E community. The JTAPIC program's unique ability to gather and analyze combat event data, injury data, and live-fire data helped to provide analytical feedback to multiple organizations with oversight of the Stryker Double V Hull. The JTAPIC program provided a specific response to vehicle PMs and evaluators to assist in conducting survivability performance comparisons to controlled Double V Hull live-fire test data.
- Ruling out injuries as a result of specific combat-related incidents can be as important as identifying an injury. In September 2011, the Joint IED Defeat Organization and OSD DOT&E had questions about head injuries from incidents involving mine rollers. The JTAPIC program was able to provide a response using the combined efforts of partners from the NGIC, the NHRC, and the Joint Trauma System.
- The Mounted Analysis Project Area responded to a May 2011 request from the Marine Corps to an Urgent Universal Needs Statement regarding specific vehicle attacks and corresponding injuries. This information was used to help determine trends and solution sets for each vehicle type.
- In response to an RFI from the Marine Corps Combat Development Command, the JTAPIC program was able to provide detailed data and analysis on specific vehicle platforms that experienced nonbreaching, underbelly attacks from mines and IEDs. These results were used to help prioritize efforts with regard to underbelly improvements and enable more informed evaluation of modeling and simulation outputs.

JTAPIC RFI submissions are now available via the RFI Management System of the Distributed Incident Collaboration Environment. In collaboration with ARL, this system will allow 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 web site enables the JTAPIC program to establish two-way communication with outside DoD and government agencies on both classified and unclassified networks, and also provides the capability to track tasks and RFI status in support of submissions, which are then traceable back to individual JTAPIC program partners.

Accomplishments

Feedback to the Field #6 – Perforation of the Sternum by an Intraosseous Infusion Device

The Defense Medical Materiel Program Office, along with JTAPIC program partners from the AFMES, and the USAISR Joint Theater Trauma System published this guidance on the proper medical procedures and medical materiel logistics considerations related to sternal intraosseous intravenous infusion devices. The presentation is available at http://www.medicalsci.com/files/feed_back_to_the_field___6.pdf.

Evaluation of Stryker Vehicle Injuries Leads to Vehicle Improvements

The AFMES, a JTAPIC program partner, conducted an in-depth analysis of injuries associated with Stryker vehicle events. Its evaluation found drivers were more vulnerable than other occupants in the Stryker vehicle. JTAPIC program partners worked with the PM Stryker to develop an under-driver improvement kit that has been placed on Stryker vehicles.

Visual Anatomical Injury Descriptor

The Visual Anatomical Injury Descriptor (VAID) is a graphical computer tool developed by the ARL to improve injury visualization and effectively communicate trauma described by medical or simulated data. The VAID user inputs injured anatomical structures or AIS codes and VAID illustrates these on the anatomy. In addition, the VAID tool supports injury frequency analysis across body regions and types of anatomic structures for multiple cases. VAID allows users to easily create detailed injury illustrations to improve image readability. Illustrations can be colored according to threat-to-life and specific anatomic structures (**Figure 3-5**).

Injury and Severity Analyses Enable Tracking of Threat Trends and Assessment of Countermeasures

The AFMES, a JTAPIC program partner, provided in-depth injury data on 304 KIA U.S. service members who were involved in blast incidents. The injuries were coded using International Classification of Diseases-9 diagnostic codes,

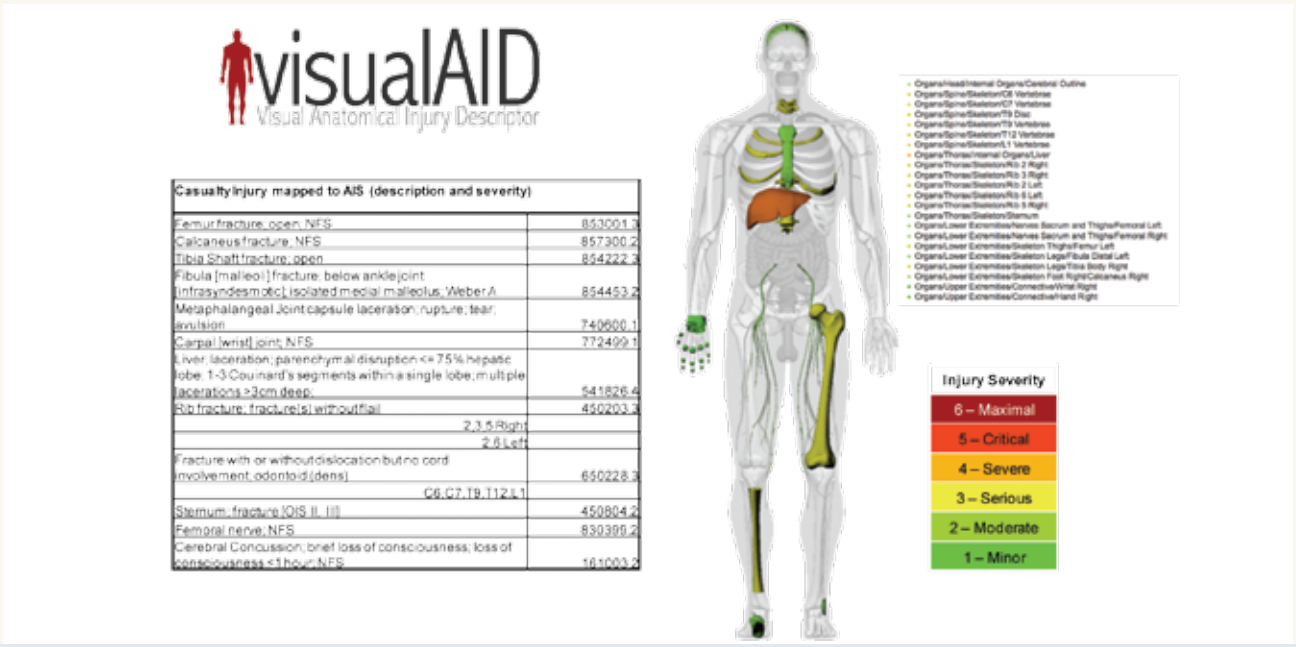


Figure 3-5. Visual Anatomical Injury Descriptor

AIS-2005 for each injury, and an overall injury severity score. These detailed injury reports were integrated with intelligence investigations and matched to the specific events. The ability to correlate injury and severity data with tactical events ensures prompt injury data get to the proper intelligence agencies and materiel communities to track threat trends and assess the effectiveness of countermeasures.

ARL Conducts Human Factors Study to Improve Its Operational Casualty Model on the Effects of Impaired Vision and Hand Dexterity on Shooting

As part of a Defense Health Program project to improve models used in the JTAPIC program, ARL conducted the first of a series of experiments to validate task-based impairment for infantry tasks that were previously approved by the U.S. Army Maneuver CoE. ARL conducted an extensive literature review and found no previous work investigating impairment of a hand or arm and the effect it would have on shooting performance. Similarly, little was found on research examining visual impairment and shooting performance. ARL generated data using human factors methods to artificially simulate impaired vision and hand dexterity and to measure the ability to perform a shooting task, which, under normal circumstances, requires the use of hands and eyes. Data collection, reduction, and analysis from the study are complete. The final technical report will be published by ARL.

ARL Characterizes Threat to Dismounted Warfighters from Shallow-Buried IEDs

ARL conducted experiments to characterize the threat from shallow-buried IEDs found in theater. The NGIC provided the threat information, which consisted of plastic jugs of homemade explosive. Using high-speed video, ARL characterized the soil velocity as it was thrown by the blast; ARL also collected BOP measurements. ARL used data from recovered geologic fragments provided by the AFMES to predict potential injuries from these threats. Classified briefings with this information have been provided to PEO Soldier to aid in its body armor development.

Casualty Clinical Profiles Used to Improve, Develop, and Prioritize Warfighter Protection

The NHRC, under the direction and guidance of the JTAPIC program and in collaboration with the NGIC, developed clinical profiles for 4,519 OIF/OEF casualties (1,771 dismounted casualties [foot patrol] and 2,748 casualties in mounted [vehicle] events). Using a system developed by the NHRC that integrates multiple real-time DoD medical, tactical, and operational casualty medical and tactical event reporting systems, NHRC assembled the medical data and coded the injuries using various diagnostic and injury severity taxonomies. The injury profiles were then mapped to the tactical events that generated each casualty. These mapped profiles were uploaded to a secure site on a weekly basis where they are available to multiple DoD injury prevention and threat reduction activities and agencies. These data are used to develop new and enhanced vehicle and body armor

designs; prioritize which vehicles and body armor components will be upgraded to higher standards of protection; and conduct and design live-fire tests that more closely approximate the nature of the insurgency threat.

Tracking Personal Protective Equipment Ensures Proper Forensic Evaluation

Forensic evaluation of PPE is crucial to the post-mortem examination of a warfighter because it allows the medical examiner to be certain that the wounds on the body correlate to the findings on the clothing and equipment worn during a blast injury and to gather any possible forensic evidence. To ensure proper forensic evaluation, the AFMES, working with PEO Soldier and the Marine Corps, is tracking the return of PPE with the remains and the PPE returned later and reassociated with a specific warfighter and a specific event. Tracking of PPE has led to improvements in PPE, such as the addition of small arms protective insert side plates and the development of an improved helmet.

Collaboration May Identify Possible Vehicle Vulnerabilities

The NGIC AAAP is collaborating with other JTAPIC program partners to assess injury data, return-to-duty status, and other pertinent crew data for more than 2,392 mounted casualties. The partnership incorporates this information into numerous RFIs and threat reports on a weekly basis. Obtaining the correct information for all casualties allows AAAP to properly inform combat units, vehicle developers, and others of possible vehicle vulnerabilities.

Armor/Anti-Armor Threat Coordinating Group

Hosted annually by the NGIC AAAP, the conference provides information to agencies and organizations involved with U.S. military vehicle programs. This includes vehicle PMs and representatives from the research and development, testing and evaluation, and modeling and simulation communities. The agenda focused on three areas: Weapons Design and Employment, Weapons Effects, and Threat Mitigation. The JTAPIC Mounted Analysis Project Area supported the Weapons Effects portion of the conference with presentations that included data analysis conducted in regard to both Stryker and Medium Tactical Vehicle Replacement vehicle platforms, an introduction to the new VAID, and the NHRC's Outcomes of Physical Injury project. AAAP personnel presented a breakdown of training-related projects, including preparation for a new aspect of battlefield vehicle forensics using three-dimensional imaging.

Canine IED Detection Effectiveness Testing

This testing was conducted at ARL after the Dismounted Analysis Project Area initiated a need for determining IED detection dog capabilities for detecting various homemade explosives. The tests were conducted in May 2011 followed by reporting in June 2011.

Dismounted Analysis Project Area

The project area's collaboration has contributed to the integration of intelligence and medical data to exploit and evaluate foreign weapons systems and positively identify new munitions in theater. The JTAPIC Dismounted Analysis Project Area has contributed products to customers on IED trends associated with dismounted casualty-producing incidents, small-arms fire attacks against dismounted service members, integrated operational data associated with gunshot wounds to the head to assist in determining current and future helmet capabilities, combat out post attack analysis to support the Research, Development, and Engineering Command's Force Protection

Sensor to Shooter Baseline Demonstration, and Green-on-Blue Analysis for the Asymmetric Warfare Group to assist in training pre-deploying units.

The JTAPIC Dismounted Analysis Project Area has conducted analysis of ballistic evidence to identify threats recovered from PPE and fallen warfighters and experiments to determine effects on PPE of behind armor debris as effects are not considered in standards for testing PPE and provided that information to PM-SPIE. In addition, the researchers performed analyses to quantify the survivability effects of replacing the Improved Outer Tactical Vest with the lighter-weight, less restrictive plate-carrier. This analysis was part of a decision briefing to the VCSA and the Secretary of the Army. The JTAPIC program conducted experiments with homemade explosive, quantifying fragment velocities and characterization of the blast, to aid dismounted analysis.

Mounted Analysis Project Area

Leveraging the strengths and expertise of the JTAPIC program partnership has resulted in providing detailed information and timely analysis to the testing and evaluation community, allowing experts to gain a unique insight on the performance of ground combat vehicles by relating injuries sustained in theater to live-fire test assessments.

The Mounted Analysis Project Area team helps to provide the intelligence community with the most significant aspect of analyzing the effects of enemy weapons using the combined JTAPIC program expertise in regard to combat-related injuries, trauma analysis, and autopsy results.

Support to Field Assistance in Science and Technology Teams

Deploying Field Assistance in Science and Technology (FAST) teams provide a mechanism for reach-back from the theater to the continental U.S. science and technology assets to address operational issues. The JTAPIC program provides a support role to FAST teams in their missions in theater. In March 2011, the JTAPIC program participated in the Research, Development, and Engineering Command's Orientation and Reach-Back Training to instruct a FAST team on how to leverage JTAPIC RFI processes.

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 is useful for decision making by combatant commanders and medical personnel, equipment design and trade-offs, as well as guiding technology and research investments. The PCO and JTAPIC program are involved in efforts to improve this knowledge base and inform stakeholders. Three efforts are described as follows: (1) a process to evaluate standards used in blast injury prevention efforts, (2) an initiative to collect blast exposure data during combat, and (3) development of a toxicology-based framework for future blast research.

Blast Injury Prevention Standards Recommendation 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's role is to advise the EA on MHS BIPS 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, such as peak force, to complex algorithms and models that address multiple components of blast insults, such as force-time history.

MHS Blast Injury Prevention Standard

Biomedically valid description of the physiologically or biomechanically based injury and performance responses of a human to blast insults.

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 community, the testing/assessment community, and medical and operational policy makers. MHS BIPS 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 vehicles, and effective protection systems.

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. Currently, there is no unbiased and inclusive process in place that takes advantage of a broad community of SMEs to identify and thoroughly assess the biomedical validity and applicability of medical standards to DoD-unique problems. Likewise, there is no process in place to approve BIPS for the DoD to ensure consistent application of the best available standards.

To support the EA's responsibility to develop and propose MHS BIPS for ASD(HA) approval, the PCO established an unbiased process for assessing MHS BIPS (**Figure 4-1**) known as the BIPSR process. The medical, test and evaluation, materiel development, and operational communities have been actively involved in this process from start to finish. There are two key components in the process to identify and approve an MHS BIPS:

- Recommendation Process: An unbiased and inclusive process, under the authority of the EA, for identifying and assessing MHS BIPS 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, through the Commander, USAMRMC, on MHS BIPS to recommend to ASD(HA) for approval and DoD implementation.

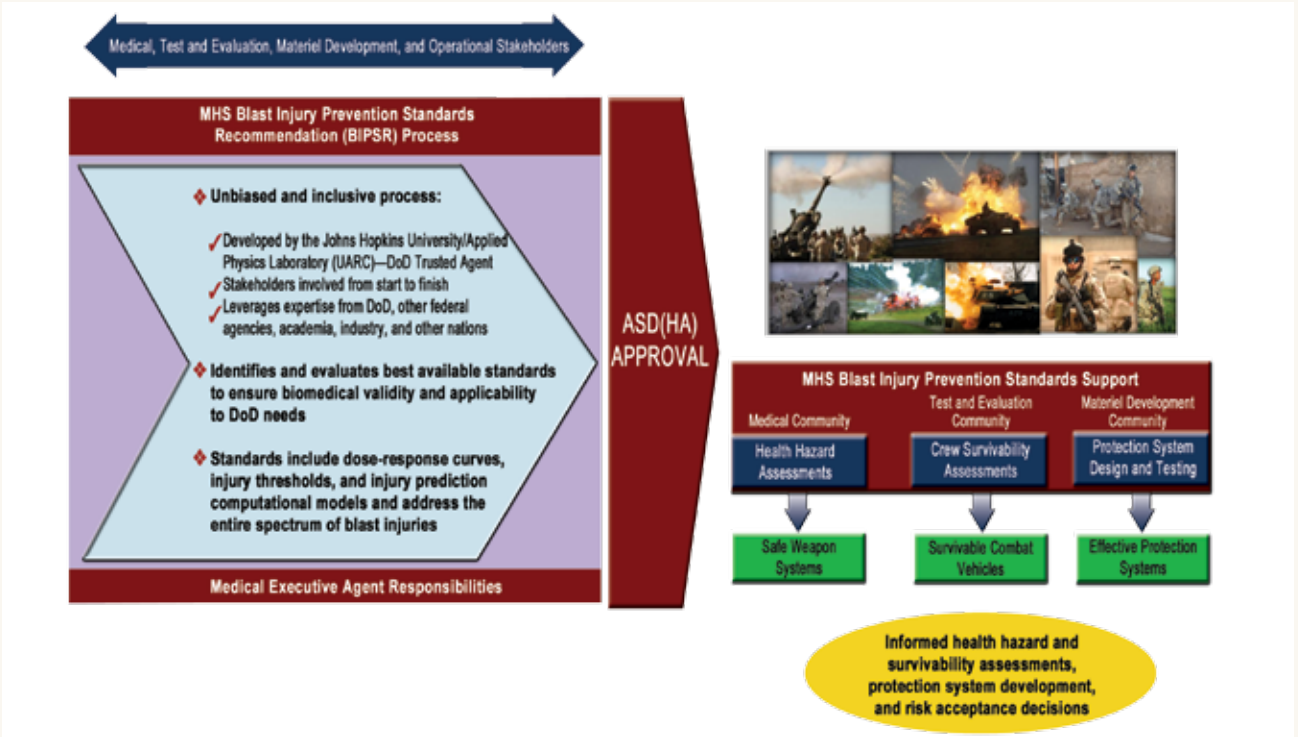


Figure 4-1. MHS Blast Injury Prevention Standard, Relationship, and Responsibilities

The BIPSR process implements the first component. 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 approach include:

- Inclusive of stakeholders from the test and evaluation, materiel development, medical, and operational communities
- Stakeholders play an active role throughout the process
- Uses SME panels that are broad-based, nonadvocacy groups composed of panel members from academia, industry, DoD, and other federal agencies
- Incorporates consensus building to recommend the best, biomedically valid standards that meet the needs of the DoD stakeholders
- Identifies gaps and research needs when suitable standards do not exist

The major pillars of the BIPSR process are shown in **Table 4-1**.

The BIPSR process is initiated by a literature review that serves two purposes: (1) to identify existing capabilities and standards pertinent to the injury under evaluation and (2) to compile a list of appropriate SMEs who may serve on the SME panel performing the evaluations. Once a list of candidate standards has been defined, the iterative nature of the BIPSR process builds layers of information about the capabilities of each candidate under consideration. The SME panel conducts the initial evaluations, giving balanced, objective, and knowledgeable advice on the candidate standard's suitability for the DoD's intended uses based on the available information. The list of candidate standards is narrowed based on an evaluation against a set of defined criteria. Information generated through the evaluation process serves as the basis for a meeting that provides a forum for stakeholders (i.e., users, analysts, and developers) to build consensus, share information, and discuss the applicability of a candidate standard to the DoD's intended use, potentially narrowing the list of candidates that move forward in the evaluation process. In some cases (e.g., for computational models), the candidate standards undergo a detailed examination of capabilities through a rigorous test process focused on stakeholder-defined test scenarios. Once the test cases have been run, the results are assessed using statistical tools. In the final step of the BIPSR process, the nonadvocacy SME panel and JHU/APL team conduct final evaluations, develop standards recommendations, and prepare process improvement recommendations.

Table 4-1. Major Pillars of the BIPSR Process

Pillar	Subprocess	Activities
I	Review Existing Capabilities	• Engage stakeholders and identify relevant standards for the injury criteria through a systematic literature survey • Establish a broad-based, independent review panel • Poll the community by conducting an RFI
II	Develop Data Collection Mechanisms	• Develop standardized evaluation and information templates • Conduct frequent panel meetings to establish review criteria
III	Develop Evaluation Criteria	• Define scenarios and evaluation metrics • Hold a consensus-building meeting
IV	Evaluate Candidate Standards	• Conduct an interactive set of evaluations with the SME panel and developers
V	Host Meeting	• Hold a consensus-building meeting for stakeholders to share information
VI	Derive and Execute Test Cases	• Involve users and stakeholders in the development of scenario-based test cases and execute the tests for the identified candidate standards (where applicable)
VII	Develop Recommendations and Evaluate Process	• Produce a report that recommends standards for PCO consideration as the basis for MHS BIPS • Recommend improvements to the BIPSR process

Collaboration is at the core of the BIPSR process and can be seen in the following core elements:

- Stakeholders Committee – Defines the problem statement and scenarios to be assessed, identifies gaps in the current standard set, drives implementation, and participates in all major decisions throughout all phases of the BIPSR process.
- SME Panel – A broad-based, nonadvocacy panel whose members are drawn from industry, academia, and government. The SMEs have experience in the domain of interest, development of the candidate standard product (e.g., dose-response curve and computational model), test and evaluation, clinical medicine, and Independent Verification and Validation.
- Stakeholder Driven Consensus-Building Meeting – A forum for stakeholders, the SME panel, users, analysts, and candidate standard developers to discuss the DoD's intended uses, gaining context and scope for the evaluation, and allowing for individual interviews with developers to gain a detailed understanding of candidate standard capabilities and/or profiles.

As part of BIPSR process development, a pilot project was conducted. In the pilot, the PCO asked the JHU/APL to review a class of injury prediction tools that address injury and performance decrements from inhalation exposures to mixed fire gases. See **Table 4-2** for a summary of the pilot project. This class of tools could be used to assess warfighter survivability in combat vehicles and other enclosures where inhaled fire gases may be a threat and to assess warfighter health risks associated with the use of weapon systems that produce toxic gases. This pilot project served to verify the BIPSR process and provided lessons learned that were incorporated into the final BIPSR process implementation. The occupational exposure risk gaps identified by the SMEs illustrate another significant value of the BIPSR process. Documented gaps can help the medical research community shape future research investments.

Finally, the PCO has met with the Defense Standardization Program Office regarding the BIPSR process for evaluating blast injury prediction tools. Developing a military standard requires that an organization be assigned as the Standardization Management Activity as prescribed in DoD 4120.24-M, "Defense Standardization Program (DSP) Policies and Procedures." As a result of the meeting, it was determined that the PCO would be ideally suited to become a Standardization Management Activity for medical military standards related to blast injuries.

Helmet-Mounted Sensor System

The objective of the HMSS fielding initiatives is to collect information on real-life combat exposures of Soldiers and marines to head impacts, including blast-related impacts, to help guide the development of head protection systems and to provide the basis for the development of objective head injury screening tools that can be used to rapidly identify warfighters needing medical evaluations from head injuries.

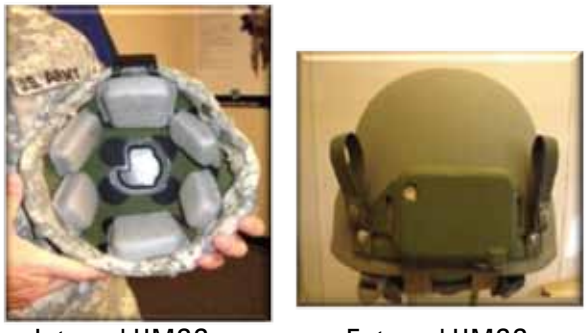
Gen I HMSS

The former VCSA directed the fielding of the Gen I HMSS to two deploying brigade combat teams. The PM SPE fielded 6,979 HMSS to the 1st Brigade Combat Team, 4th Infantry Division (OIF) and 4th Brigade Combat Team, 101st Airborne Division (OEF) between December 2007 and February 2008 (**Figure 4-2**). Additionally, the Marine Corps' PM ICE fielded 1,952 HMSS to two deployed marine battalions. The PM SPE fielded two Gen I HMSS variants, one mounted externally on the back of the Advanced Combat Helmet and the other mounted internally in the crown. 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

Table 4-2. BIPSR Process Pilot Project: Injury Prediction Tools for Toxic Gas Inhalation Exposure

BIPSR Process Pilot Project: Injury Prediction Tools for Toxic Gas Inhalation Exposure
Process: • Performed an in-depth literature review and published solicitations in journals and newsletters to identify relevant injury prediction tools • Established a broad-based, nonadvocacy, independent review panel co-chaired by the JHU/APL Project Manager and a representative from the OSD DOT&E • Conducted panel meetings to establish review criteria • Facilitated in-depth reviews of candidate injury prediction tools by the panel • Hosted a consensus conference in February 2011 with tool developers and stakeholders • Worked with key Army, Navy, and Air Force stakeholders to develop detailed test cases with realistic scenarios and toxic gas exposure data • Performed head-to-head assessments of the candidate tools for each of the test cases
The SME panel identified four relevant inhalation injury prediction tools for evaluation: • ABC (developed by the ARL) • BURNSIM (developed by USAMRMC and the U.S. Air Force Research Laboratory) • EXODUS (developed by the University of Greenwich, United Kingdom) • TGAS (developed by USAMRMC)
Findings: • The panel concluded that TGAS has the biomedical validation and capabilities that stakeholders would need to accurately assess health and performance risks from inhaled fire gas exposures to support personnel vulnerability and survivability assessments. • However, none of the tools is adequate for assessing health and performance risks from occupational exposures, such as the risks associated with the use of weapon systems that produce toxic gases. This gap requires additional research.



Internal HMSS External HMSS

Figure 4-2. First-Generation Helmet Mounted Sensor Systems

analysis project. The JTAPIC data analysis project team included USAARL, L-3 Communications/ Jaycor (under contract to USAMRMC), and the NHRC. The objectives of this project were to (1) assess the reliability and accuracy of HMSS, (2) establish a method for translating HMSS data into meaningful impact or blast "doses" to the head, and (3) correlate the calculated head doses.

The Gen I HMSS project was the critical first step in developing an objective exposure monitor/head injury screening tool and providing information to guide the development of future head protection systems. 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. The research teams recommended to the VCSA to field the Gen II HMSS only if all lessons learned from the Gen I HMSS are applied. The PM SPE has initiated actions to acquire, test, and field the Gen II HMSS.

Gen II HMSS

The Gen II HMSS is a PEO Soldier initiative designed to provide an objective way to measure and record Soldier head impact and blast exposures in combat and training environments. Lessons learned from the Gen I HMSS fielding led to improvements incorporated in the Gen II HMSS fielding and data collection plans. BAE Systems

(HEADS) is participating in the Gen II HMSS (**Figure 4-3**). In a blast or head impact event, the sensors measure and record helmet acceleration and blast pressure. The sensor system measures linear and rotational acceleration in three axes each, generates event data files based on preset threshold triggers, and has an operational battery life of 12 months (rechargeable via USB). The HEADS system has pressure sensors, but due to performance and reliability issues recorded pressure data will provide little to no value for this effort. These sensors are not medical devices, and they are not used to diagnose TBI; however, they do provide a means for documenting potentially injurious head impact and blast exposures, and they provide a mechanism for rapidly identifying Soldiers who should be referred for medical evaluation and treatment.

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

Figure 4-3. Second-Generation Helmet Mounted Sensor System

Approximately 45,000 Gen II HMSS will be fielded to six brigade-sized units deploying to Afghanistan. The PM SPE fielding team will install sensors into new Advanced Combat Helmets and field them to warfighters prior to mission rehearsal exercise. Field service representatives, controlled by PM SPE, will be embedded with each battalion to assist with downloads and provide hands-on technical assistance. The JTAPIC program team will analyze Gen II HMSS data to determine if the Gen II HMSS acceleration data can be used to confidently predict head injuries. The JTAPIC program will apply existing data analysis tools and techniques, such as a mathematical helmet-to-head acceleration transfer function developed in Gen I.

The JTAPIC program has also developed an operational exposure screening tool that will be used to rapidly screen sensor data as they are downloaded from Soldiers' helmets. The screening tool produces a Red-Amber-Green output indicating the probability of a concussion based on existing concussion data from the automotive safety community and the National Football League. Soldiers with Amber or Red events will be referred for medical evaluation in accordance with the existing DoD policy on the management of concussion/mTBI in the deployed setting.

The DARPA Blast Gauge

The Rochester Institute of Technology, under contract with DARPA, developed a blast gauge to identify warfighters who have received relevant blast exposures with the ultimate goal of providing exposure-tailored treatment. The data-logging

device measures pressure and resulting head acceleration and provides a time stamp to aid in correlating blast events with injuries. The VCSA approved a pilot fielding of the blast gauge to a brigade deployed to Afghanistan in 2011. The JTAPIC program will be analyzing data from this sensor as well as providing a common link among the various sensor development efforts.

NATO Technical Activity Proposed for Environmental Toxicology of Blast Exposure

The HFM-207 Symposium on "A Survey of Blast Injury Across the Full Landscape of Military Science" was held on October 3–5, 2011. The PCO Director was a co-chair of the NATO Research and Technology Organization's HFM Panel program committee that organized the symposium. The symposium served as an initial assessment of the state-of-the-science for understanding blast injury and highlighted the need for continued cooperation among NATO countries regarding research on blast exposure.

In essence, the symposium fulfilled the role of an HFM exploratory team, and it was suggested that the HFM Panel recommend new Technical Activity Proposals. A Technical Activity Proposal has been

submited for establishing a group focused on a toxicological approach to blast injury. This would be a 3-year effort starting in early 2013. Countries anticipated to be involved in the effort are the United Kingdom, Canada, The Netherlands, and the United States. This effort 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. Specific objectives include:

- Building an evidence-based outline for NATO standards for blast injury analysis
- Examining opportunities for improvements in the standards of medical care for blast injury
- Exploring advancing the state-of-practice in computational modeling of blast injury in relevant operational environments
- Exploring standardized animal models and toxicology research protocols that could be adopted by research and technology programs across NATO

Table 4-3 lists some of the proposed topics to be considered under this effort. If approved, this new Technical Activity could make significant contributions to setting research agendas, advancing blast science, and ultimately improving blast exposure metrics/monitoring and the design of blast protection systems, such as vehicles and PPE across NATO countries.

Table 4-3. Projected Topics

Topics to Be Addressed
Toxicology methods relevant to understanding blast exposure effects
Physics-based modeling of animals and man in blast environments
Physiological modeling of animals and man in blast environments
Standardized toxicology protocols for blast exposure 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
Toxicology methods and metrics
Survey of blast research infrastructure and identification of cross-NATO research opportunities

Chapter 5

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

Our 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 without head impact including: blood vessel tearing and hemorrhage, mechanical or immune-caused breakdown of the blood–brain barrier, 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 deregulation 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 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 to elucidate injury mechanisms and determine the effectiveness of protective or treatment strategies.

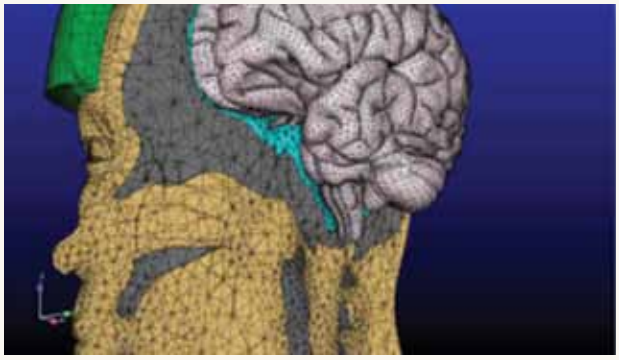
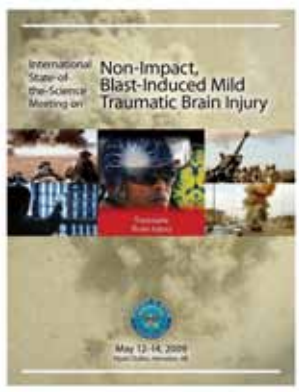


Photo credit: Reuben Kraft, U.S. Army Research Laboratory

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, such as gas and structure dynamics, biomechanics, physiology, pathology, biology, biochemistry, and time and space scales. In the

past 2 to 3 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 there are some major challenges 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 blast exposure and non-impact, blast-induced 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 (**Table 5-1**) 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

Table 5-1. DoD Brain Injury Computational Modeling Expert Panel

Co-Chairs: Mr. Michael Leggieri and Dr. Raj Gupta DoD Blast Injury Research PCO	
Dr. James Atkins Walter Reed Army Institute of Research	Dr. April McMillan Oak Ridge National Laboratory
Dr. Ibolja Cernak Johns Hopkins University Applied Physics Laboratory	Dr. David Moore Tulane University
Dr. Michael Deeds Naval Surface Warfare Center, Indian Head Division	Dr. Willy Moss Lawrence Livermore National Laboratory
Dr. Ralph DePalma Department of Veterans Affairs	Dr. Andrzej Przekwas CFD Research Corporation
Dr. Frank Doyle University of California, Santa Barbara	Dr. Raul Radovitzky Massachusetts Institute of Technology
Dr. Ramona Hicks National Institute of Neurological Disorders and Stroke	Dr. Douglas Smith University of Pennsylvania
Dr. Reuben Kraft Army Research Laboratory	Dr. James Stuhmiller L-3 Communications/Jaycor
Dr. Hwee Nah Tan DSO National Laboratories, Singapore	Dr. Erik Takhounts U.S. Department of Transportation
Dr. Bruce LaMattina Rutgers University	Dr. Liying Zhang Wayne State University
Dr. Peter Letarte Department of Veterans Affairs	

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

March 2010

At this meeting, the Expert Panel developed a working definition of a validated computational model of non-impact, blast-induced mTBI. The Expert Panel divided non-impact, blast-induced mTBI into three components: (1) pathways into the brain (i.e., through the skull, through soft tissue, skull acceleration, distortion of skull, and surge), (2) internal damage (i.e., neurons, axons, microtubules, pressure, and cavitation), and (3) outcomes (loss of memory and consciousness). It also developed a list of challenges to be addressed and reviewed two of these:

- **The lack of mechanical dose-response models of brain tissue dysfunction.** The Expert Panel recommended developing definitions of functional and physical failure (on all scales). It suggested obtaining information on high strain rates, functional failure, and the degree of failure. Finally, it recommended obtaining a consensus from researchers in this area.
- **The lack of validated constitutive models for the material properties of brain tissue, skull, and cerebrospinal fluid, particularly for large strain rates and perfused tissue.** The Expert Panel recommended obtaining a consensus from researchers with relevant state-of-the-art expertise in material properties. It also suggested holding a discussion focused on the results of studies funded by the DoD.

August 2010

At this meeting, the Expert Panel focused on computational modeling efforts at the cell, tissue, and organ levels aimed at understanding the injury mechanism of non-impact, blast-induced mTBI. Developing and validating these models are a key need. **Figure 5-1** maps out one pathway

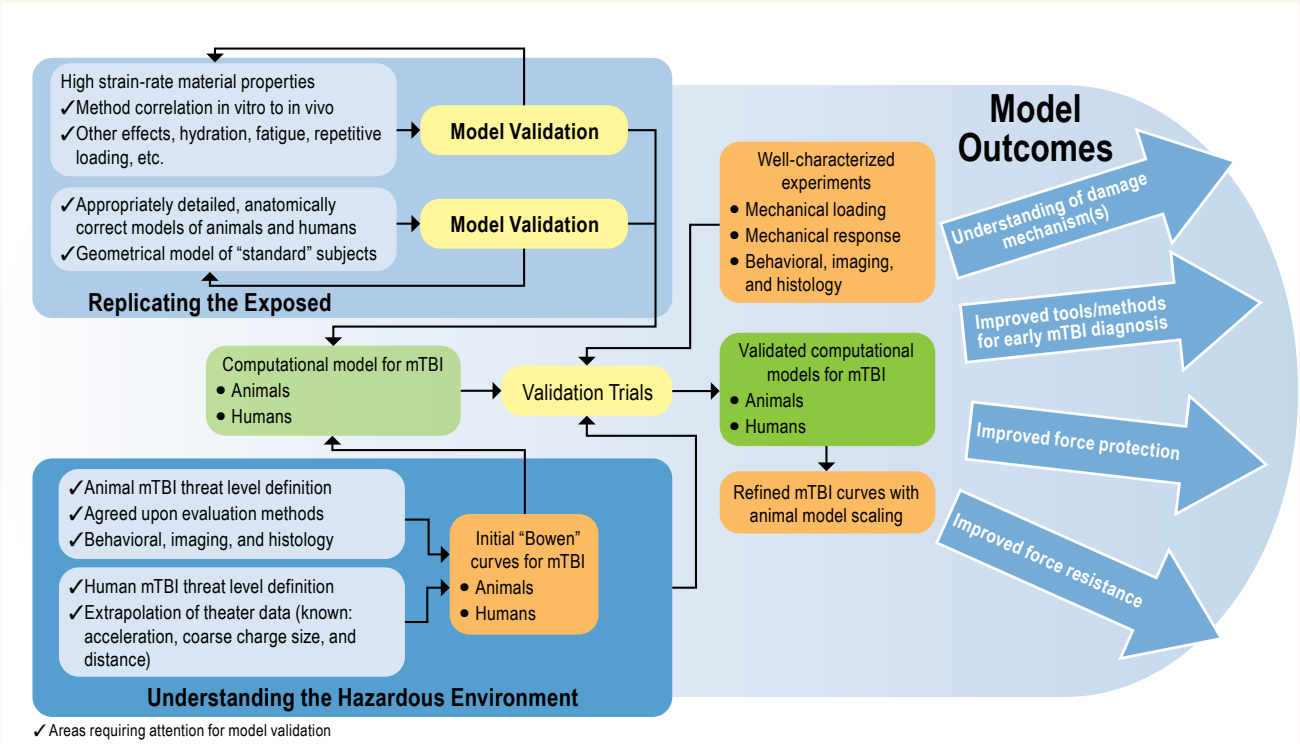


Figure 5-1. Pathway to Validating an Animal or Human Model of mTBI

to validating an animal or human model of mTBI. Overall recommendations of the Expert Panel included focusing on the subcellular level and developing three-dimensional models of soft/brain tissue, developing a data repository of scaled imaging models of the central nervous system, and further exploring soft tissue modeling. The Expert Panel reviewed five challenges related to the meeting theme and made specific recommendations to address these challenges:

1. **Modeling impact (obtaining the correct parameters for contact and friction) between brain and cranium.** The Expert Panel recommended validating animal and human brain models (in parallel) for the large amplitudes and short durations seen in non-impact, blast-induced mTBI; determining the physics that need to be captured; collecting brain/cerebrospinal fluid/cranium data, in vivo shear and strain data, and tissue modeling data; obtaining guidance from the medical community (interdisciplinary interactions will accelerate model generation); and encouraging innovation in sensor technology.
2. **Developing benchmark-loading paradigms to facilitate model comparison and validation.** The Expert Panel's recommendations included conducting benchmarking experiments for both existing and newly developed models to establish cross-communication and validation among models, developing a finite number of benchmark-loading paradigms that satisfy the standard baseline for experimental and computational efforts, and developing increasingly complex physical head models under both militarily and clinically relevant instrumented blast-loading conditions with the ultimate goal of developing a full human head model.
3. **Developing adequate models of tissue response/mechanical injury (material failure).** The Expert Panel's recommendations were to validate the injury mechanism in a controlled environment (e.g., inside a human head), recreate military- and blast-relevant loading conditions representative of a waveform transmitted to the brain, and develop precise, real-time temporal monitoring for the detection of acute biophysical disruptions, pathological mechanotransduction, and ultrastructural failure.
4. **Modeling soft tissue.** The Expert Panel recommended focusing on the microscale architecture of brain cells as well as the mechanochemical properties of the trauma induced by blast, identifying alterations of soft tissue properties based on whole-body conditions, characterizing primary blast forces in the field, developing tissue-based injury models that reflect the loading conditions computed by FE models of primary blast, testing the predictive value of FE models by recreating conditions of military-relevant physical scenarios, and establishing a subgroup of the Expert Panel to further explore soft tissue modeling.
5. **Exploring the issue of cavitation.** This phenomenon is the formation of microcavities within a body tissue due to the force of a blast wave. The Expert Panel suggested conducting inertial-loading studies on large animal models and shock-loading studies on cadavers, conducting studies to demonstrate whether microcavitation exists at militarily and clinically relevant levels, and correlating head size and load between animal models and humans.

December 2010

This meeting of the Expert Panel focused on animal modeling, Department of Transportation modeling efforts, epidemiology of blast injury, and clinical

aspects of mTBI. The Expert Panel reviewed three challenges related to animal modeling of primary blast-induced mTBI and made specific recommendations to address these challenges:

1. **Developing criteria for animal models that reproduce injury (determining end points).** The Expert Panel recommended integrating clinical and epidemiological testing with animal testing, identifying the most important problems models have to answer, mimicking the physics of a real-life situation as closely as possible, sharing computational models as well as experimental test data, obtaining consensus on what is required for validating animal models, and developing methods of visualizing and quantifying neuronal damage in the brain following blast-induced mTBI.
2. **Establishing linkages to neurobiology.** The Expert Panel's recommendations were to identify the neurobiology underlying blast-induced mTBI functional deficits/symptoms in Soldiers, develop models that are based on specific functional problems and incorporate the military-relevant environment, define the grade of an injury and the neurological outcome so that a model prediction in relation to the injury can be defined, and conduct whole animal experiments as cells often behave differently in vivo versus in vitro.
3. **Establishing solid models across multiple geometric scales.** The Expert Panel recommended validating the FE and computational models across multiple scales to address the issue of scaling both existing and newly developed protective gear to animal models and to accurately scale and interpret results from animal to humans. Two- and three-dimensional models of the brain are needed that will allow researchers to address questions relevant to the medical problem.

March 2011

The fourth meeting of the Expert Panel focused on soft tissue modeling, biomechanics, and related challenges, such as solving brain biomechanics equations using FE method solvers for soft tissue (overcoming numerical difficulties). The Expert Panel also initiated planning for the development

of a roadmap for a computational model of non-impact, blast-induced mTBI. Challenges reviewed by the Expert Panel during the meeting and its specific recommendations to address these challenges are summarized as follows.

1. **Soft tissue modeling.** The Expert Panel recommended evaluating existing models; determining the material properties for various regions of the brain; characterizing biologically relevant interfaces such as skull/cerebrospinal fluid/soft tissue; understanding the relationships between strain, shear stress, and pressure; determining the effects of repetitive blast on material properties; and developing tools to measure blast parameters without disrupting tissue. Also noted was a need for standardization among models (outputs, variables, etc.), datasets from multiple laboratories, and the development of common terminology between the medical and engineering communities.
2. **Solving brain biomechanics equations using FE method solvers for soft tissue (overcoming numerical difficulties).** The Expert Panel recommended the development of new FE model solutions for conditions that are typical of blast effects on the head but that can cause computational difficulties or errors in existing models. These include fluid/solid interactions, porous media models, models with damage incorporated into them, virtually incompressible materials, and inaccuracies in the pressure gradients. The Expert Panel also recommended

conducting parametric analyses of the models across variable loading conditions and establishing benchmark test cases to evaluate potential failure modes of the models.

September 2011

This meeting focused on the development of 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, and each developed a computational roadmap approach. The Expert Panel reviewed each of the four approaches at the meeting and made recommendations toward an integrated approach. The DoD Blast Injury PCO drafted an integrated roadmap after the meeting that incorporated the approaches and recommendations of the Expert Panel. The PCO also developed definitions of the nomenclature that is relevant to the computational model. Following development of the integrated research roadmap, 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.

Expert Panel Consensus Statement

"Physical surrogates and mathematical models can play important roles in understanding the physics of blast and developing research hypotheses, but they will not predict blast-induced mTBI until the injury mechanisms are understood."

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.

Attributes of the Computational Model
Accurately predict non-impact, blast-induced mTBI

- Be anatomically and pathophysiologically correct (i.e., biofidelic)
- Exhibit consistent material and biological properties
- Answer the problem as proposed
- Be based on experimental data using animal models
- Be representative of exposure conditions that warfighters experience
- Have a well-defined framework (including carefully defined nomenclature and taxonomy)
- Be scalable to humans and eventually multiscaled (nested hierarchical model)
- Predict injury (in animals)
- Corroborate in vitro and in vivo models
- Incorporate input/guidance from the medical community
- Include the concept of coupling fields (weak and strong coupling)
- Have the ability to capture empirical data

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. **Figure 5-2** shows a schematic of the approach to validating the computational model. 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 5-3**.

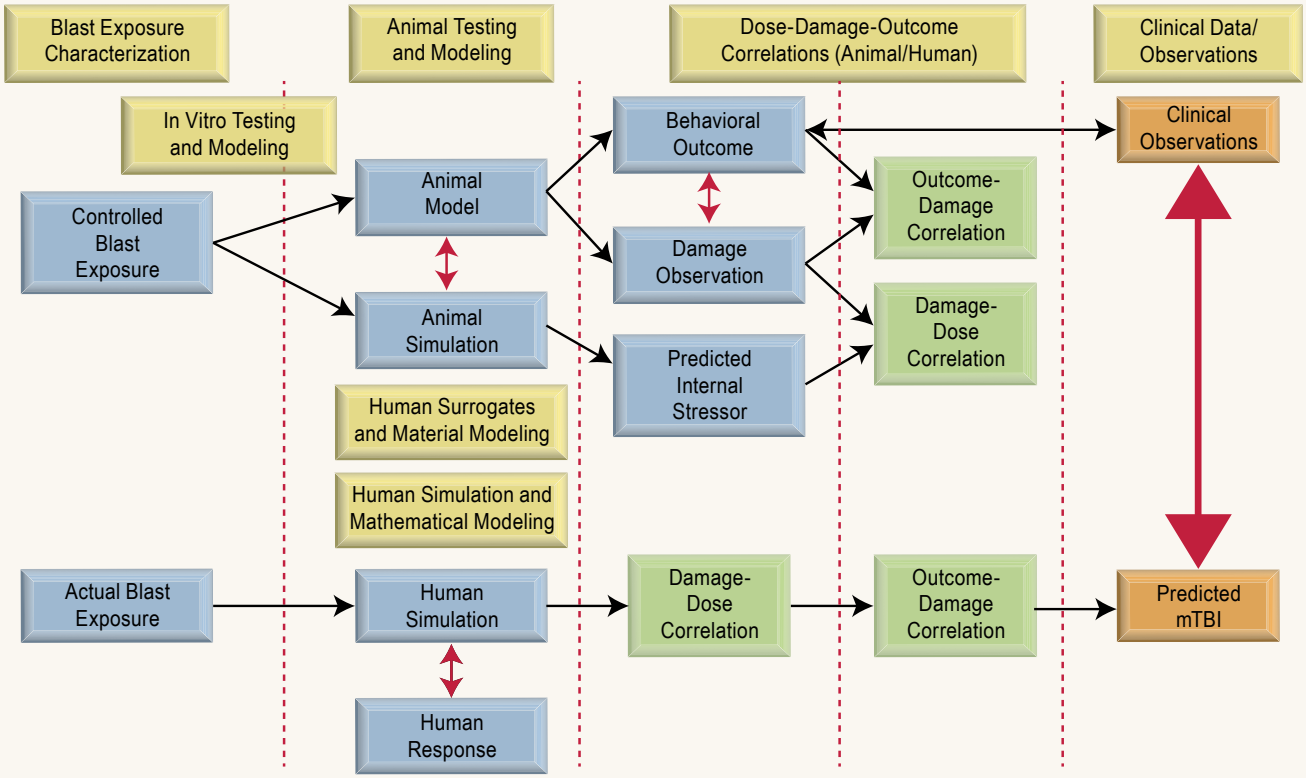


Figure 5-2. Computational Modeling Validation Schematic

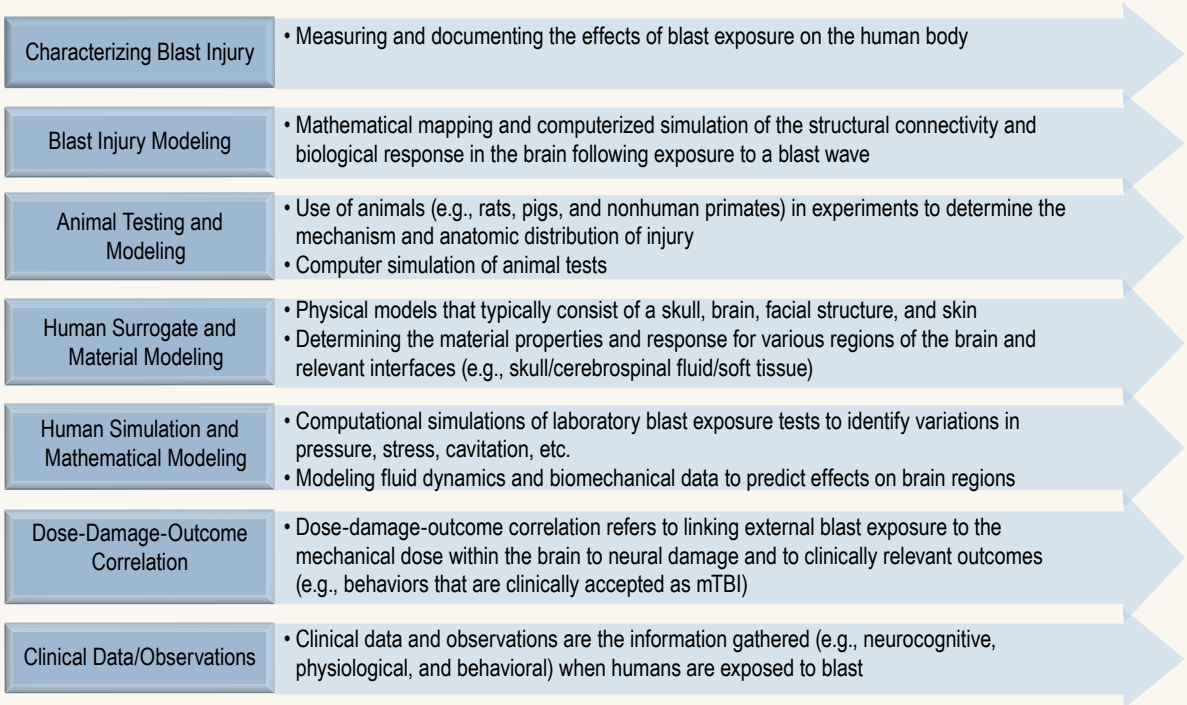


Figure 5-3. Roadmap for Computational Modeling

An enterprise approach is envisioned to achieve these objectives. The enterprise (depicted in **Figure 5-4**) 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 and provide quality assurance, minimize duplication and free resources for novel research, keep the work focused on the solution, and to evolve with the research.

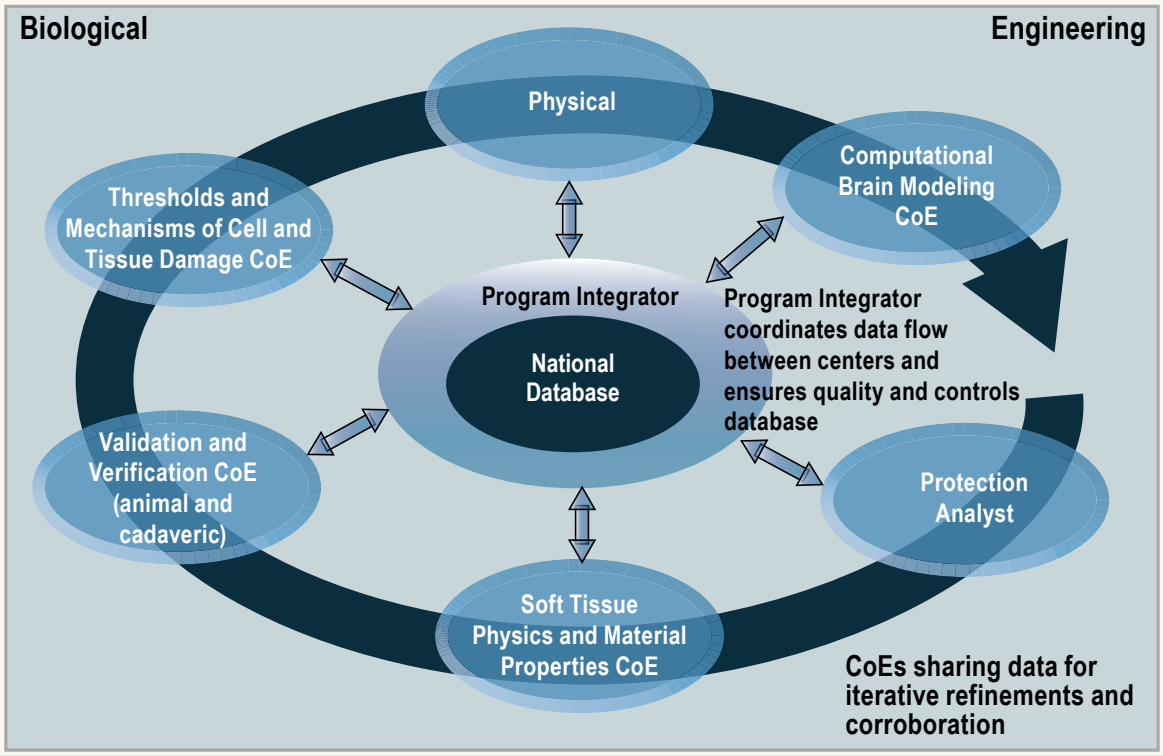


Figure 5-4. The Computational Blast-Induced mTBI Modeling Enterprise

Chapter 6
State-of-the-Science Meeting Series

The Blast Injury Research PCO established a State-of-the-Science Meeting Series 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 DCoE and Joint Technology Coordinating Groups 5, 6, and 8 (Military Operational Medicine, Combat Casualty Care, and Clinical and Rehabilitative Medicine, respectively).

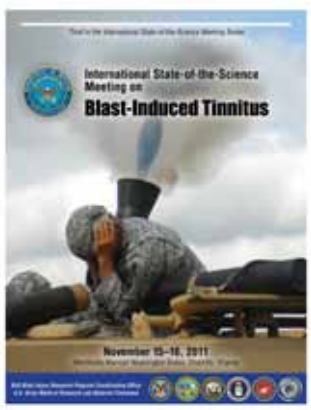
Since inception, three State-of-the-Science meetings have been hosted. Meeting summaries can be found on the DoD Blast Injury Program web site at https://blastinjuryresearch.amedd.army.mil.

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. An average of 15,000 new cases of tinnitus were reported each year in active-duty service members from 2007 to 2010,[1] and tinnitus and hearing loss were the top service-connected disabilities in veterans receiving compensation in FY11.[2] Tinnitus and hearing loss are significant medical and cost issues for both the DoD and VA.

[1] Helfer, Thomas M. Noise-Induced Hearing Injuries, Active Component, U.S. Armed Forces, 2007–2010. *Medical Surveillance Medical Report (MSMR)* 18(6):7-10, June 2011. (http://www.afhsc.mil/viewMSMR?file=2011/v18_n06.pdf#Page=7)

[2] Veterans Benefits Administration, Department of Veterans Affairs. Annual Benefits Report Fiscal Year 2011. (http://www.vba.va.gov/REPORTS/abr/2011_abr.pdf)



The DoD Blast Injury Research PCO, in collaboration with the DoD HCE and the VA, hosted the International State-of-the-Science Meeting on Blast-Induced Tinnitus on November 15–17, 2011 to assess current knowledge regarding the cause, diagnosis, and treatment of tinnitus and to identify research gaps for further investigation.

More than 100 experts in tinnitus treatment and medicine were gathered from the international community, including the DoD, VA, NIH, academia, medicine, and industry, and from eight countries. An Executive Panel, led by Dr. Richard Salvi of the Center for Hearing and Deafness at the State University of New York at Buffalo, formulated key findings and recommendations for tinnitus research. The meeting also served to foster collaboration among researchers and inform DoD research investment strategies.

Key Findings

Neurological Basis for Tinnitus – Sufficient understanding of the mechanisms and factors involved in the initial onset of tinnitus and the development of chronic tinnitus, while extensively studied, still remains elusive. Changes in auditory brain pathways, auditory input signals, and the interaction with nonauditory brain areas all influence neural processing and can lead to or affect the perception of the tinnitus phenomenon. This key knowledge gap impacts the ability to develop effective preventive measures and treatments for tinnitus.

Post-Traumatic Stress Disorder and Tinnitus – The available evidence was insufficient to define a contributory linkage between tinnitus and PTSD in either direction. An indirect relationship may exist through an association of both disorders with brain injury.

Tinnitus Diagnosis and Characterization – The primary means of diagnosing tinnitus relies on subjective patient reports of tinnitus presence, loudness, annoyance, and change over time. A number of techniques are being explored for diagnosing and characterizing tinnitus, including structural and functional imaging, electrophysiological measures, and sound-based testing to identify key markers for tinnitus. Appropriate tinnitus measures are also needed in animals to support preclinical studies. The lack of standardized, objective diagnostic and characterization tools for tinnitus is a major gap in the ability to conduct clinical evaluations of existing and novel treatment approaches.

Tinnitus Treatment – Treatment of tinnitus is not standardized. Currently, no drugs are U.S. Food and Drug Administration (FDA) approved for the treatment of tinnitus. Numerous therapeutic strategies have been proposed or are in use in recent years, using devices, existing drugs approved for other indications, behavioral therapy, and psychotherapy, alone or in combination. There is a need to differentiate between tinnitus management and treatment in evaluating the success of a strategy. Well-controlled studies of existing and novel strategies are needed to inform and standardize clinical practice guidelines.

Recommendations for Research

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

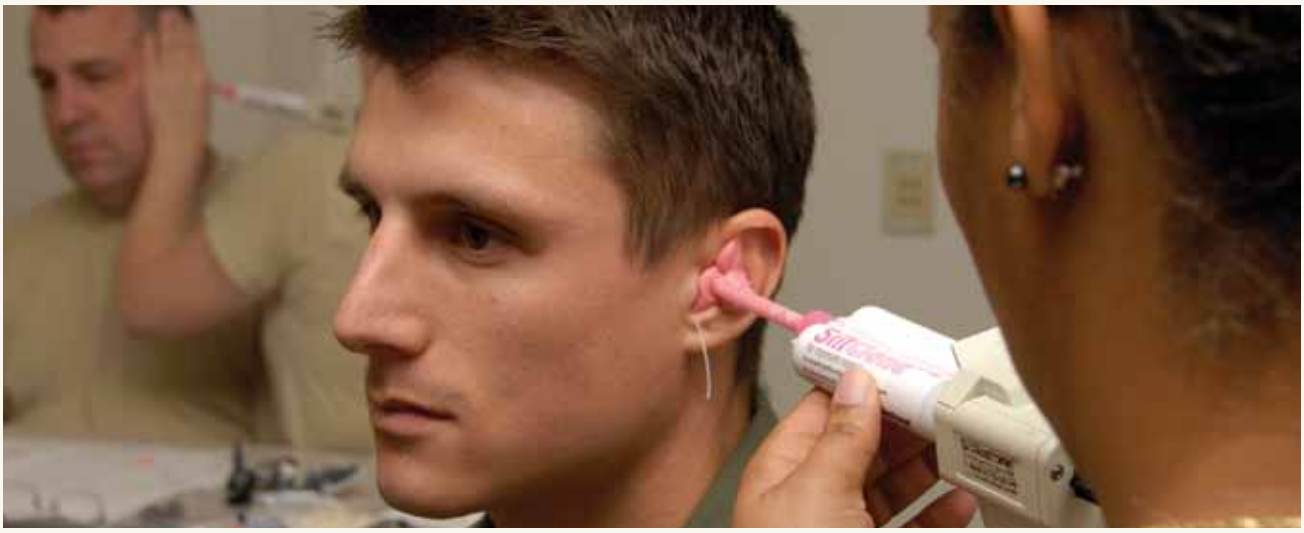
- Identify candidate pharmacologic strategies for early interventions that could prevent the cascade of damage to the cochlea and brain from leading to hearing loss and tinnitus.
- Develop improved and new imaging techniques to identify functional and structural changes that could be used to diagnose 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.

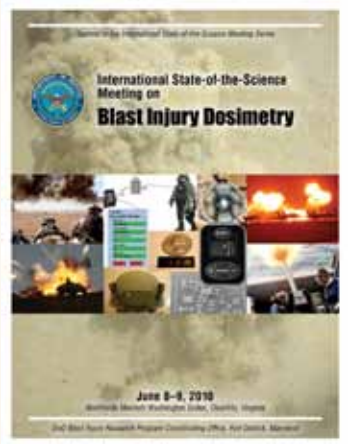
Recommendations for Current Medical Capabilities

- Develop a centralized education and outreach center to serve both clinicians and patients to support improving care models.
- Establish standardized DoD and VA clinical practice guidelines and information sources for the diagnosis and treatment of tinnitus using currently available technologies and practices, and adjust these guidelines as new technologies and practices are developed and validated.



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, BOP, impulse noise, and inhaled toxic gases. The DoD is seeking a way to objectively record and document blast-related exposures and to correlate these exposures with acute injuries or chronic health effects.



The DoD Blast Injury Research PCO hosted the second meeting in the State-of-the-Science Meeting Series on June 8–9, 2010 in Chantilly, Virginia. This meeting focused on blast injury dosimetry: the ability to record and document blast-related exposures and correlate these exposures with acute injuries or chronic health effects.

The objectives of the meeting were to:

1. Identify and prioritize the blast injuries of concern that should be the focus of the DoD's blast dosimeter development efforts.
2. Determine if there are blast dosimeters available that can be fielded now or within the next 2 years.
3. 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.

The key questions addressed during the meeting were:

1. What blast injuries are we interested in addressing with dosimeters?
2. What exposure data are needed to predict the likelihood of the injuries of concern?
3. What sensor technologies are available to address the required data elements?
4. What biomedical research has been done, or is required, to develop human effects models that correlate the blast-related exposures (sensor data) with resulting injuries?

A panel of experts helped synthesize data from the presentations and working groups to generate conclusions that identify current capabilities and research gaps for future research initiatives.

Knowledge Gaps

There are knowledge gaps regarding the ability to record and document blast-related exposures and correlate those exposures with acute injuries or chronic health effects. These gaps include:

- An objective measure of actual exposure to blast effects
- An understanding of the mechanisms of blast injury and how they affect the nature of the resulting insult or injury, including:
  - The range of inputs applicable to human injury
  - Individual variations in susceptibility to injury
  - Appropriate data for predicting injuries of concern
  - Scaling research results for animal models to humans
  - Differentiating between blunt versus blast injury
  - The effects of repeated blast exposures
  - The effect of multiple injuries
  - Linking pressure and acceleration data to the injury
- A correlation of data from blast physics dosimeters with devices that measure biological responses ("responsimeters")
- Diagnostic tests to differentiate among physiologic sources of mTBI, PTSD, and chronic pain
- Delineation of the role of toxic gas inhalation and other factors on mTBI
- Validation and correlation of biomarkers with blast injury (e.g., peripheral blood markers for neuronal injury or galanin message-associated peptide)
- Well-characterized pressure and time-history data (multipoint measurements)
- A data fusion system for managing and streamlining all data that are being generated
- Sensors that are fast, can record meaningful data, and are able to decouple pressure from acceleration
- Lightweight, inexpensive, and battery-free blast wave sensors
- Sensor networks and suites that can collect data on the environment (i.e., sensor fusion)

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 second generation of 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.

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.

Findings

- Current working definition of mTBI does not meet the needs for clinical assessment of brain injury.
- Evidence from clinical and animal studies that non-impact, blast-induced mild trauma to the brain can occur.
- Insufficient evidence to support one mechanism of insult and one physiological response as the most plausible explanation for the association of non-impact blast exposure with mTBI.
- Insufficient data on the nature of non-impact, blast-induced mTBI to make recommendations on how to better protect Soldiers.
- Knowledge gaps include: blast components/thresholds leading to injury, computational and analytic models, human neuropathological data, and evidence-based recommendations to inform protection, mitigation, and treatment approaches for blast-related mTBI.

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.
- 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.

A sampling of the research presented at this meeting was published in a special *Supplement to NeuroImage*, Vol 54, Supplement I, 2011.

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 within the DoD. In addition to these DoD organizations, many other federal agencies as well as academia and industry are playing key roles in solving blast injury problems. A sampling of FY10–FY11 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

A Clamp That Stops Junctional Bleeding

Stopping major bleeding from junctional areas of the body, such as the groin or under the arm, remains a significant challenge because tourniquets cannot be applied effectively to those regions. Working with a former Special Forces medic, USAISR orthopedic surgeons and scientists evaluated a new clamp for treating junctional bleeding. This device gives medics the ability to intervene in some injuries where a tourniquet cannot be applied and may stop bleeding and potentially death from hemorrhagic shock during the earliest stages of care and transportation for hospital treatment. This clamp was recently cleared for use by the FDA and is in use by U.S. Army Special Operations Forces.

Tactical Wheeled Vehicle Survivability Army Technology Objective

The Tactical Wheeled Vehicle Survivability (TWVS) Army Technology Objective concluded its efforts in early FY11. Through systems engineering analysis, three common elements were identified to achieve the survivability mission: (1) integrated armor solutions, (2) non-armor technologies, and

(3) modeling and simulation tools. The TWVS Army Technology Objective provided PMs and commanders in the field with the ability to rapidly tailor TWV protection levels as required by mission. The effort's undertakings are captured in the Survivability System Deskbook, retained at the TARDEC, to serve as a decision-making knowledge base of capability packages available to the PMs. The Survivability System Deskbook provides recommendations for survivability solutions across the entire TWV fleet.

TARDEC's Heavy Equipment Transporter Automatic Fire Extinguishing System

In a partnership with PM Heavy Tactical Vehicles, TARDEC developed the Automatic Fire Extinguishing System (AFES). TARDEC's expertise in the development and testing of fire extinguishing systems allowed the rapid acquisition of the necessary engineering, materials, and testing services to develop an AFES tailored to the geometry of the Heavy Equipment Transporter's (HET's) crew compartment. This system will aid in answering vehicle fire issues from theater involving the HET vehicle on convoy missions and will therefore serve to minimize injuries resulting from fires. The result of this effort was a qualified AFES that leveraged components from other vehicles in the Army fleet. The HET AFES design is now documented in a Technical Data Package, and the systems have been integrated to the HETs deployed to theater. Additionally, the HET AFES has also been designed for compatibility with the M1070 A1 HET variant.

Product Alert on Aluminum Silicate-Based Hemostatic Agents

Scientists at the USAISR found that a product using an aluminum silicate-based hemostatic agent (ASHA) was effective in stopping high rates of bleeding from an artery, but they were concerned that the material could have adverse side effects. Using a cell culture system of endothelial cells, such as those that line the inside of blood vessels, they confirmed that all ASHAs are directly toxic to these endothelial cells. This led to an alert to the field not to purchase ASHAs for use in stopping bleeding. The results were published in the *Journal of Trauma* in an article entitled, "Toxicity of Aluminum Silicates Used in Hemostatic Dressings Toward Human Umbilical Vein Endothelial Cells, HeLa Cells, and RAW267.4 Mouse Macrophages."

Injury Prevention – Injury Mechanisms

Disruption of Neuronal Membranes by Primary Blast Waves

In collaboration with the Armed Forces Institute of Pathology, researchers from the Defense and Veterans Brain Injury Center have used a computational model to better understand the mechanism of brain injury caused by blast. This model simulated the blast wave interaction with molecular models of myelin membranes under physiological conditions. Myelin membranes are responsible for proper communication between neurons. A unique method was developed to generate various intensities of BOP and velocity. A typical pressure range observed during explosive blasts is 600 to 1,000 kPa (kilopascal). Simulations show that in this pressure range, blast wave velocity is a key factor in membrane damage. When subjected to velocities larger than 600 m/s (meters per second), the membrane's lipid bilayer (a two-layered sheet of fatty acids) splits down the middle. Such structural changes could lead to diffuse axonal injuries, which may correspond to the pathology of blast injury. The

methods developed will be used to understand the mechanisms for more complex cellular structures responsible for different cognitive functions.

Characterizing the Response of the Head and Brain to Blast Waves

Investigators at Wayne State University have been funded by the PH/TBI Research Program to characterize the response of the head/brain to the effects of blast waves produced by various explosions using a sophisticated, anatomically inspired simulation of the human head. The researchers found that within the brain, the highest pressure was sustained by the frontal cortex, followed by the parietal cortex. They evaluated maximum principal strain responses at different cortical regions and the brainstem and found that the brainstem had the highest strain response. The investigators also demonstrated that the effects of being adjacent to a reflecting wall are noticeable only on the region of the brain closest to the wall. They conducted studies to evaluate the relationships between external blast insults and localized brain responses. They found that increases in intracranial pressure and strain in the frontal cortex were strongly and positively correlated to peak blast pressure.

Repeated Exposures to Stress and a Single Blast Elicit Long-Lasting Behavioral, Molecular, and Neuronal Abnormalities in Rats

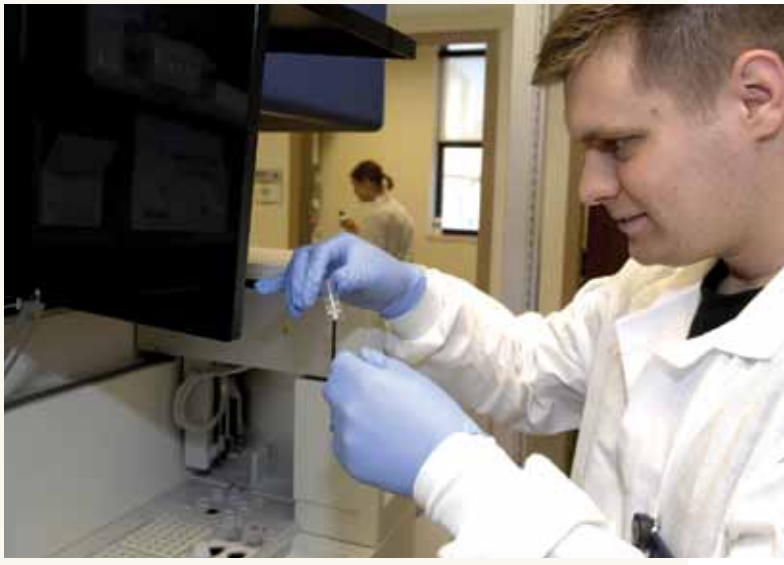
Investigators at the USUHS in conjunction with the Congressionally Directed Medical Research Programs have shown that exposure of rats to repeated stress causes a short and transient increase in anxiety but no significant memory impairment and no significant cellular and molecular changes. In contrast, when stressed animals were also exposed to a single blast event, they showed lasting behavioral, molecular, and cellular abnormalities characterized by memory impairment, neuronal cell losses, inflammation, and gliosis (proliferation of glial cells in the damaged area).

Evaluating the Cumulative Effects of Single and Multiple Air Blast Exposures in Rats

The mTBI and cognitive impairments observed among many of the troops returning from OIF and OEF may result from repeated exposures to explosive blast. Scientists at the Walter Reed Army Institute of Research, through an award from the PH/TBI Research Program, are using a preclinical model of BOP to evaluate and compare the cumulative effects of single and multiple air blast exposures on neurologic status, neurobehavioral function, and neuropathological characteristics. The researchers demonstrated that rats exposed to single blasts exhibited less pronounced neuronal degeneration, specifically in the cerebellar white matter and optic tracts, compared to rats exposed to repeated blasts.

Assessing Pressure-Mediated Effects on Blast-Induced TBI

Researchers at the NHRC have been funded by the PH/TBI Research Program to focus on identifying potential pathways in which blast energy is transferred to brain tissue using microfiber pressure sensors in addition to detecting blast wave propagation through the body using a rat model of blast injury. The researchers exposed rats to a moderate level of BOP and observed a differential effect of blast exposure with respect to the animal's orientation to BOP. Measurement of the pattern of the shock wave in animals indicated higher shock wave amplitude in the brain with a head-on orientation. They also observed differences in the shape of the shock wave with respect to the orientation of the head when exposed to BOP, suggesting that shock waves can enter the body and tissues from different angles



and are reflected by surrounding tissues and change shape. Ultimately, data generated from current and future investigations can be applied to the better design of protection against the effects of BOP on the brain and body.

Injury Prevention – Injury Models

Models of Blast- and Concussion-Induced Tinnitus

Blast- or concussion-induced TBI is often associated with tinnitus, which is a perception of bothersome sound in the absence of external stimulation. About 3 to 4 million veterans have tinnitus and up to 1 million seek clinical services to relieve this condition. When tinnitus is combined with post-traumatic stress, the underlying condition can disrupt daily living and negatively affect one's emotional well-being. Researchers at Wayne State University have been funded by the Defense Medical Research and Development Program to develop an animal model of tinnitus. They found that blast-exposure leads to significant behavioral evidence of tinnitus compared to non-blast-exposed control animals. The researchers also found that blast exposure led to increased firing rates of neurons in some regions of the brain and decreased neuronal firing rates in other brain areas.

Generic Vehicle Hull Testing

The generic hull was designed to be a representation of an actual Army ground vehicle without duplicating any specific vehicle. Because of the generic design, data developed during live-fire exercises with the generic hull are not classified and can be shared with partners in industry and academia. As such, the generic hull can be utilized as a platform for testing occupant protection technologies (e.g., seats, floor paddings, and airbags), sensor technologies (e.g., black boxes and instrumentation), and other vehicle components without the need for a formal contract between the vendor and the government. During FY11, TARDEC-Ground System Survivability refurbished a generic hull that was used in a previous test and built two additional generic hulls. In late FY11, TARDEC-Ground System Survivability partnered with industry, academia, and the military to conduct testing using one of the generic hulls. The results from the test were used by the partners and the DoD's WIAMan program to examine the performance of test dummies in UBB events and to refine the requirements for the WIAMan program. Further tests using the remaining two generic hulls are planned for FY12.

Using Digital Image Correlation to Dynamically Measure Deformation on the Inside of Helmets

The ARL developed a means to experimentally replicate and "dynamically" measure helmet back-face deformation using digital image correlation. Data collected could be potentially correlated to injury criteria as the military medical and modeling communities develop greater understanding of injury mechanisms. ARL recognizes that correlation of injury to physical response measurements is a technology gap that currently exists, and there is a need for additional research in this area. To assist with closing this gap, ARL demonstrated the accuracy and utility of digital image correlation as a useful technology and methodology for ballistic helmet evaluation. ARL continues testing on various Army and Marine Corps helmets. ARL developed instrumentation and methodology that permits robust, repeatable, behind-armor data to be collected on helmets. The

warfighter payoff is an experimental methodology that aids in the design of helmets to minimize the potential for blunt trauma injury and maximize helmet resistance to penetration.

Blast/Trauma Mitigation for Combat Helmets

The effectiveness of helmet systems in protecting against blast injury is being studied using a novel system called the Human Surrogate Head Model (HSHM). The HSHM was developed by the JHU/APL as a physical surrogate capable of wearing helmets and capturing important biomechanical relationships for understanding blast injury. The HSHM contains a state-of-the-art instrument suite to describe pressure dose

to the head, resulting overall head movement, and internal brain response (pressure and displacement). Researchers at JHU/APL used the HSHM in repeatable tests to evaluate the effect of different helmet systems to blast response in both laboratory and live-fire environments. A prototype helmet system was developed that can reduce peak head acceleration by 20% under blast loading conditions when compared to the current baseline Advanced Combat Helmet fitted with pads manufactured by Team Wendy. The prototype consists of the airframe helmet developed for the Special Forces fitted with an eye shield and a new type of cushioning liner based on the anti-blast and shock reduction buffer technology developed by L-3. Shock tube testing was used to demonstrate that the liner system can provide better cushioning capability than the Team Wendy liner system. Computational fluid dynamics simulations were used to develop the eye shield design to provide much improved protection against frontal and side blasts. Finally, field testing was carried out to validate the performance of the prototype helmet system.

Developing a Realistic Model of Blast Exposure in the Mouse

Investigators at the University of Alabama at Birmingham have been funded by the PH/TBI Research Program to simulate blast scenarios with full-scale dynamic modeling and develop a dynamic mouse model of blast injury that will incorporate scaled human stress and strain rates and evaluate blast-exposed mice to determine the neurological and pathological sequelae of blast exposure. The researchers found that a 0.588 joule impact–acceleration injury produced a significantly longer duration of transient unconsciousness and an increase in anxiety but did not induce vestibular motor deficits or affect learning in the mice. Looking at the effects of BOP exposure on behavioral outcomes in mice, the investigators found that blast-exposed mice displayed a significant increase in time until return of auditory response, tactile response, and termination of dazed behavior compared to nonexposed mice. They also determined that learning and memory were not altered by a single blast exposure.

Simulating Blast Injury to the Human Head

Researchers at the University of Washington have been funded by the PH/TBI Research Program to develop software for a three-dimensional, comprehensive, and multiscale numerical model capable of accurately simulating the complex physical processes involved when a shock wave impinges on the human head. The model will include effects deriving from pure shock propagation, absorption, cavitation, and bubble dynamics, as well as those associated with the elastic stresses generated in the skull and brain. The researchers have developed a self-contained, complete software package that allows simulations of both acoustic and elastic wave propagations on a realistic dataset of biological structures.

The software is physics based and accounts for shock wave propagation, reflection, refractions, and frequency-dependent losses. Although the software in this project specifically targets the human head region, it is flexible enough for use with any other segmented region in the body.

Acute Treatment – Diagnostics and Epidemiology

Developing Diagnostics for the Rapid Assessment of TBI

Recent investigations demonstrate that a number of protein biomarkers, exclusive to head injury, are released into the bloodstream in response to head injury. The quantities of these biomarkers are directly proportional to the severity of injury. Although diagnostic protocols for determining the quantities of TBI biomarkers in the blood exist, time and logistical constraints limit their utility in rapidly diagnosing and triaging injured warfighters in the field. Thus, with funding from the PH/TBI Research Program, SFC Fluidics is developing a portable and field-deployable handheld device capable of measuring biomarker quantities using a finger-prick blood sample to assess the presence and magnitude of a TBI. Thus far, the researchers have optimized the detection of the TBI biomarkers, S100 calcium-binding protein B (S100B) and glial fibrillary acidic protein (GFAP), with a portable benchtop instrument. In addition, they have developed an intermediate-sized handheld prototype to identify and troubleshoot potential technical and quality control issues before completing the final prototype. Ultimately, it is anticipated that this deployable handheld device will assist in providing a rapid diagnosis with respect to the presence and seriousness of TBI in warfighters in the field.

Mechanisms of Damage in Brain After Blast Injury

Neuronal and glial proteins detected in the peripheral circulating blood after injury can reflect the extent of the damage caused by blast TBI (bTBI). The temporal pattern of serum levels can further predict the severity and outcome of the injury. As part of characterizing a large-animal model of bTBI, investigators at USUHS determined the changes in the serum levels of S100B, neuron-specific enolase, myelin basic protein, and neurofilament heavy chain (NF-H). The investigators observed a sudden increase in serum NF-H levels following bTBI. If additional studies verify the investigators' findings, the observed early peak of serum NF-H levels could be developed into a useful diagnostic tool for predicting the extent of damage following bTBI.

Identifying Markers That Track with the Severity and Type of Brain Injury

Investigators at Banyan Biomarkers, Inc., have been funded by the Peer Reviewed Medical Research Program to identify and characterize

biochemical markers of brain injury, using an integrated, proteomics-based approach. They used brain, cerebrospinal fluid, and plasma samples from five groups of rats: naïve, sham, moderate, severe, and delayed lethal penetrating ballistic brain injury. They assessed the samples for the presence of four biomarkers: spectrin breakdown product 150 (SBDP150), SBDP145, ubiquitin carboxy-terminal hydrolase L1 (UCHL1), and GFAP. SBDP150 was elevated in all sample types concomitant to level of injury. Similarly, SBDP145 tracked injury level very well 1 day post injury. Although not as robust as SBDP150, levels of UCHL1 were significantly elevated in the plasma of both the severe and delayed lethal penetrating ballistic brain injury groups. Cerebrospinal fluid levels of UCHL1 were only elevated in the delayed lethal penetrating ballistic brain injury group. Finally, GFAP was very effective at tracking injury level when measured in the cerebrospinal fluid 1 day after injury. GFAP differed from SBDP150 in that it rose first in cerebrospinal fluid and later in the brain.

A Fully Integrated Neuropsychiatric Support System May Identify Individuals at Risk of Delayed-Onset Psychiatric Disorders Following mTBI

USUHS researchers have developed a Fully Integrated Neuropsychiatric Support System (FINSS) to identify physiological measures of poor resilience to delayed-onset psychiatric symptoms due to mTBI. The FINSS responds to requirements for a technology that can identify individuals at risk of presenting significant delayed-onset neurologic and/or psychiatric disorders (including PTSD and major depressive disorder) following mTBI and for a rugged, portable system that can support a broad spectrum of neurological and psychiatric diagnoses and monitoring functions. The laboratory at USUHS and other off-site laboratories use FINSS technology for data collection from healthy controls and individuals who have sustained mTBI.

Acute Treatment – Hemorrhage and Blood

Treating Hemorrhage with Combinations of Blood Products in a Swine Model

With much interest in the proper ratio of plasma to red blood cells in treating casualties who have severe bleeding, researchers at USAISR performed studies to evaluate different combinations and ratios of blood products in pigs subjected to an uncontrolled hemorrhage spleen injury model. The researchers demonstrated that generally the use of any blood product for initial resuscitation improved survival when compared to a standard colloid solution that contains no blood-clotting factors or oxygen-carrying capacity.

Evaluating the Potential for Small Molecules to Treat Hemorrhage in a Swine Model

Working with DARPA, scientists from USAISR developed a conscious, sedated, sexually mature swine hemorrhage model to evaluate small molecules that could be used in low volumes to treat casualties on the battlefield. It was demonstrated that small-volume adjuncts, such as estrogen or poloxamer (P1880), could improve survival after severe hemorrhage. However, animals did not survive as long as those treated with Hextend® (180 minutes). In addition, P188 was also found to inhibit blood coagulation, illustrating the importance of evaluating any product used to resuscitate casualties for effects on bleeding.

Developing a Portable Blood Treatment System for Use in Combat Situations

In combat situations, fresh whole blood may be transfused without any donor screening and without standard viral testing. Deployment Related Medical Research Program-funded researchers at Terumo BCT are developing a pathogen reduction technology for whole blood that can reduce the risk of infectious disease transmission and unwanted transfusion reactions. Their portable treatment system is based on the Mirasol® Pathogen Reduction Technology System, which uses riboflavin and ultraviolet light to reduce pathogens and leukocytes in whole blood products. The researchers performed studies of pathogen kill and blood component quality as a function of volume, hematocrit, and mixing speed using canine parvovirus as the test pathogen. They found that hematocrit had the greatest effect on canine parvovirus reduction, followed by the interaction of hematocrit and volume and volume alone. The investigators will therefore include hematocrit as a specification parameter in whole blood-specific software. They also examined bacterial reduction at low titers, mimicking what would be expected in a unit of donated blood. In a 7-day study, treatment from the Mirasol Pathogen Reduction Technology System resulted in substantial reduction in bacterial growth and delayed the onset of bacterial regrowth in treated units by 1 day versus controls.

Increased Oxygen Supply to the Brain After Blast Exposure May Improve Outcomes

Decreased oxygen supply to brain regions after blast exposure is a potential mechanism of neuronal damage. Perfluorocarbon is an oxygen therapeutic that can maintain functional oxygen levels in sensitive brain tissue during low blood flow situations and can even deliver oxygen via plasma flow where red blood cell oxygen delivery has been compromised. Researchers at Virginia Commonwealth University, funded by the Office of Naval Research, showed that administration of a perfluorocarbon emulsion improved vestibular motor skill after exposure to a single moderate composite blast event in an animal model. They also found that when the perfluorocarbon was given acutely after a single moderate composite blast event, followed by exposure to a second moderate composite blast event 24 hours later, improved cognitive outcomes were observed in comparison to control animals that received saline. Further research demonstrating safety and efficacy in humans may lead to a point of injury treatment option in the far-forward battlefield environment.

Acute Treatment – Wound Repair and Stabilization

Sealing Penetrating Eye Injuries Using Photoactivated Bonding

Penetrating eye injuries from IEDs are not uncommon in current military conflicts. Lacerations to the cornea and sclera require immediate, waterproof closure to stabilize the wound and prevent endophthalmitis (infection of the intraocular cavity), which can cause permanent loss of vision or loss of the eye itself. Researchers at Massachusetts General Hospital have been funded by the Deployment Related Medical Research Program to assess an advanced technology called photochemical tissue bonding (PTB) as a potential alternative for sutures or cyanoacrylate glue for treating ocular lacerations. In PTB, a green laser activates the immediate formation of molecular bridges between a layer of amniotic membrane and the surface of the eye without collateral damage, and the eye can heal without further intervention. Importantly, PTB may be quickly administered by physicians without extensive ophthalmologic training due to its simplicity, and it may more effectively preserve the vision of wounded warriors in combat. The researchers have begun optimizing PTB for treating penetrating eye injuries in a rabbit model. Corneal sealant components, such as the amniotic membranes, dye, and clinical laser source, were tested to optimize photobonding conditions, resulting in bonding that could withstand intraocular pressures up to 10 times higher than normal.

Fracture-Resistant Stent Graft for Vascular Trauma

Published reports from recent conflicts indicate that blood vessel injuries to troops are five times higher than previously thought. Currently, the best minimally invasive stent therapies are highly susceptible to infection, stenosis (abnormal narrowing), and failure. AFIRM-funded researchers at the Cleveland Clinic, in partnership with Peritec Biosciences, Inc., have developed two stent designs, each of which is lined with bovine peritoneum to reduce the risk of stenosis. The fracture-resistant stent overcomes material fatigue issues when used in young patients, and the bioabsorbable stent offers the promise of a blood vessel repair that becomes fully integrated with, or replaced by, the patient's own tissue. The results from animal studies at 30 days post graft were promising. Industry partners are continuing to develop the stent designs with the intent of obtaining FDA approval.

Treating Severe Burns with an Engineered Skin Substitute

AFIRM-funded scientists at Lonza Walkersville, Inc., have developed an engineered skin substitute for use in severe burns (>50% total body surface area). This product is engineered from expansion of the patient's own cells over a period of 3 weeks. If successful, the engineered skin substitute may speed the healing of those with severe burns, reduce the length of hospital stays, reduce morbidity and mortality associated with infection, and spare severe burn victims the pain, incapacity, morbidity, and scarring associated with extensive donor site harvesting. A safety and efficacy study of autologous engineered skin substitute to treat partial- and full-thickness burn wounds is expected to begin in 2012.

Intravenous P12 to Limit Burn Injury Progression

Burn wounds often become more extensive—deeper or wider—over the day or two following the original insult. No approved or effective treatment is available to slow or stop that progression. Burns that initially looked easily treatable may become large enough or deep enough that skin grafting is necessary and complications of infection, scarring, and wound contracture become more likely. AFIRM-funded researchers at Stony Brook University, in association with NeoMatrix Formulations, have developed intravenous P12, a peptide that has been shown to limit progression

of deep partial thickness burn wounds. They have developed an analytical method to detect the peptide following administration and are beginning to understand its mechanism for inhibiting burn injury progression. During the next 1–2 years, the investigators will perform studies in preparation for a submission to the FDA and the initiation of a Phase 1 clinical trial. If successful, this product could reduce scarring, disfigurement, and dysfunction in wounded warriors with thermal injuries.

Nanoparticle Delivery to Inhibit Scar Formation During Wound Healing

Scientists at the Allegheny-Singer Research Institute, funded through the AFIRM, are using nanoparticles to deliver molecules into wounds. The researchers identified a gene (CCT-eta) that is elevated in adult wounds. They developed a nonviral, nanoparticle-mediated delivery system that selectively decreases the expression of CCT-eta in complex adult wounds. They found that this therapy effectively inhibits scar formation without any deleterious effects on wound healing. The researchers are currently investigating whether ultrasound-mediated gene transfer can be used in conjunction with their technology to enhance their results.

Developing Therapies That Attenuate the Wound Inflammatory Response

Researchers at the University of Pittsburgh's McGowan Institute for Regenerative Medicine were funded through the AFIRM to develop novel anti-inflammatory therapies aimed at improving the quality of healing following burn injury. The research team has demonstrated that early, short-term topical treatment with the anti-inflammatory agents nimesulide and prostaglandin E2 attenuates the wound inflammatory response, which leads to the promotion of healing.

Acute Treatment – Wound Infection

Antimicrobial Resistance Determinant Microarray for Wound Infection Prevention and Management

Multidrug resistance has been an issue in current conflicts, and the timing and selection of antimicrobials are critical to controlling infection in traumatic wounds. Researchers from the U.S. Naval Research Laboratory, in conjunction with the Naval Medical Research Unit-3 (Egypt) and the Walter Reed Army Institute of Research, and funded by the Military Infectious Diseases Research Program, have developed the

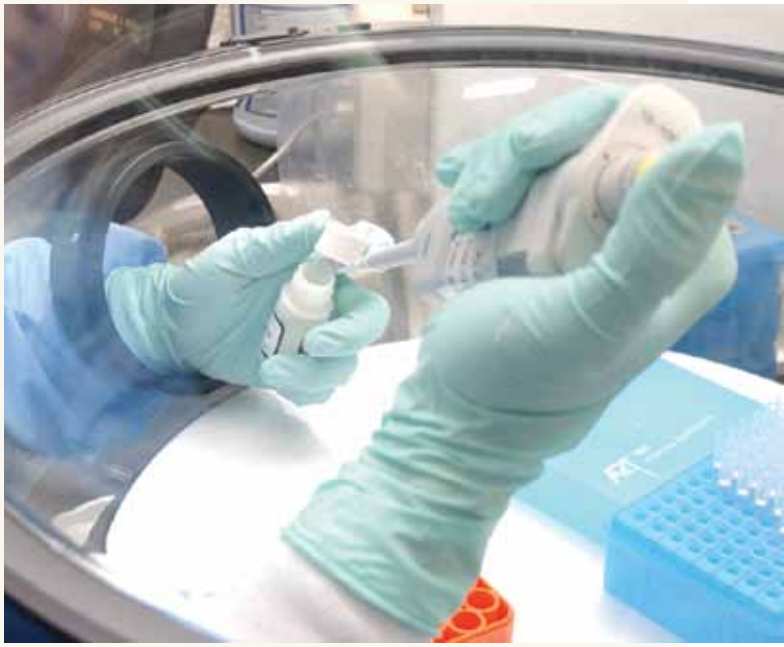
antimicrobial resistance determinant microarray to detect more than 250 antibiotic-resistance genes to 12 classes of antibiotics. Differing patterns of resistance can be detected in clinical isolates from Egypt and Iraq/Afghanistan. The microarray can provide information on species and geographic differences and can track the spread of resistance determinants. The researchers will continue to refine the design of the microarray and expand the number of resistance-associated genes that can be detected with it. They will also evaluate the system in a far-forward setting. The ultimate product will be a tool to rapidly identify pathogens and antibiotic resistance at the earliest stages of treatment and improve wound outcomes.

Treating War-Related Burn and Wound Infections with Predatory Bacteria

Researchers at the University of Medicine and Dentistry of New Jersey, with support from the Deployment Related Medical Research Program, have evaluated the ability of *Bdellovibrio bacteriovorus* and *Micavibrio aeruginosavorus* to attack bacteria commonly found in war-related burn and wound infections. *B. bacteriovorus* was able to reduce the viability of 87 of the 105 host bacteria examined as well as multispecies cultures. *M. aeruginosavorus* reduced 145 of the 177 host bacteria examined. The predatory bacteria were also able to attack biofilms that generally mirrored the host range specificity of the predator. The addition of degrading enzymes with the predatory bacteria increased the effectiveness over that of the predatory bacteria alone.

Complexed Iodine May Treat Burn Skin and Soft Tissue Wounds

A research team at the New Jersey Center for Biomaterials, funded through the AFIRM, has developed a novel antibacterial dressing containing complexed iodine for the treatment of burn skin and soft tissue wounds. They achieved promising results in initial porcine-infected burn trials with the new wound dressing. The polymer exhibited good antimicrobial activity with little biological



reactivity, and dressing changes incurred no trauma to the skin-generating wound bed.

Targeted Prevention and Treatment of Bacterial Biofilm Infections of Severe Burns and Wounds

Recurrent infection of severe wounds, specifically burns, contributes to deployment-related morbidity and mortality. The bacterium *Pseudomonas aeruginosa*—the most important cause of wound and burn infections—can form a self-encased community called a "biofilm," thereby making conventional treatments difficult. The influx of white blood cells (neutrophils) at the site of injury can cause further tissue damage and increase the formation of biofilms. In an effort to limit this influx and the formation of *P. aeruginosa* biofilms, Deployment Related Medical Research Program-funded researchers at National Jewish Health Hospital are testing the effectiveness of a novel dual therapeutic approach combining the anti-inflammatory N2 peptide with the antibiotic azithromycin. Thus far, they have demonstrated a decrease in post-burn wound severity and early *P. aeruginosa* wound infection by briefly stopping the influx of neutrophils to the site of thermal injury.

Acute Treatment – TBI Treatment

Prevention of Post-Traumatic Epilepsy Secondary to Penetrating Brain Injury

Post-traumatic epilepsy occurs in 50% of patients suffering penetrating brain injury. Through an award from the Peer Reviewed Medical Research Program, researchers at the Walter Reed Army Medical Center are conducting a study to identify agents to prevent post-traumatic epilepsy by examining the ability of free radical scavengers, such as lipoic acids and nitrones, to prevent seizure development in both the acute and delayed ferric chloride-induced seizure models. Studies have shown iron deposits in brain tissue taken from patients with post-traumatic epilepsy. These deposits may lead to the formation of harmful reactive oxygen species. The researchers demonstrated post-insult neuroprotective effects of nitrones against ferric chloride-induced seizures in vivo. Additionally, volumetric analysis of MRI data revealed a strong neuroprotective trend of the immunosuppressant drug cyclosporin A against ferric chloride-induced neuronal loss.

Delivering Drugs via Nanoparticles to Vulnerable Neurons Following TBI

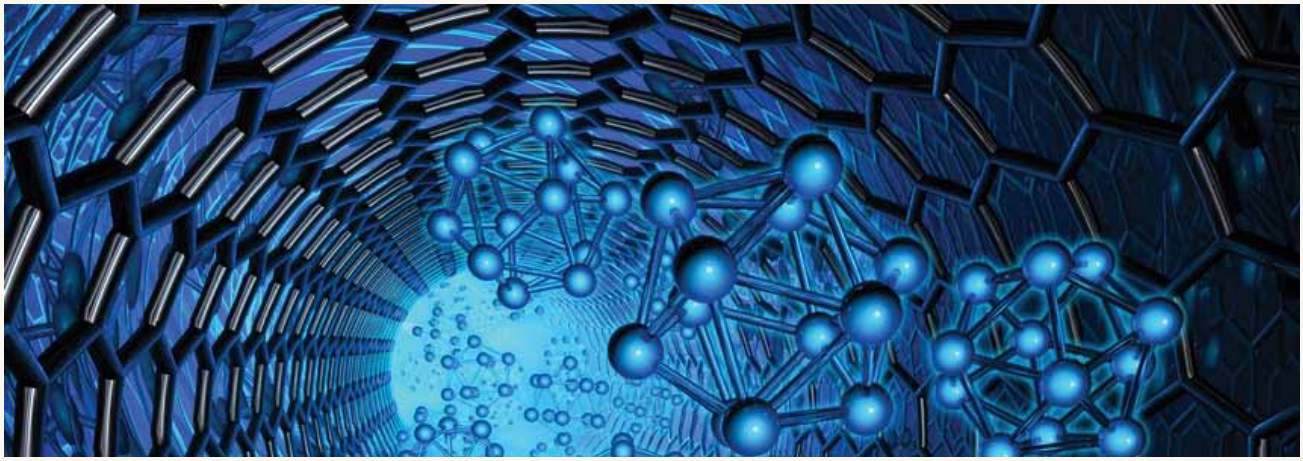
Researchers at Banyan Biomarkers, Inc., have been funded by the Deployment Related Medical Research Program to construct very small particles called nanoparticles that can encapsulate drugs and specifically deliver them to neurons at risk of dying following a moderate to severe TBI in rats. The investigators were able to integrate fluorescent markers into the polymer matrix of the particles. They used these markers to show that the particles were internalized by the target cells. NR1-functionalized particles exhibited a 50% increased uptake into cortical neurons compared to particles coated with immunoglobulin G. The dispersion shown within the cell body of the markers indicated digestion of the particles and delivery of its contents to the neuron. Collectively, these data suggest that NR1-functionalized nanoparticles will increase the delivery of the specific drug into the neurons following an injury.

Estradiol Provides Neuroprotection to Rats with TBI

Investigators at the University of Alabama, through an award funded by the PH/TBI Research Program, demonstrated 17-beta estradiol to be a neuroprotectant that can reduce the progressive damage following controlled fluid percussion TBI in rats. Learning tests demonstrated a benefit to the TBI-injured rats that were given estradiol compared to rats not given estradiol. Cerebral perfusion pressure, intracranial pressure, and the partial pressure of brain oxygen were improved in the estradiol-treated TBI-injured rats compared to untreated TBI-injured rats. Progressive brain cell death was also reduced in TBI-injured rats given estradiol compared to untreated TBI-injured animals in a dose-dependent manner.

Low-Level Light Therapy for TBI

Low-level light therapy (LLLT) can protect tissue from damage, reverse cell toxicity, reduce inflammation, and stimulate healing in a number of injury states. Preclinical and clinical data have revealed that, following stroke, brain damage



is reduced, and neurological performance in both animals and humans is improved following noninvasive application of transcranial LLLT. Researchers at Massachusetts General Hospital conducted experiments to test the efficacy of LLLT in ameliorating the neurological deficits induced by two models of impact-related TBI. In both models, the beneficial effects of the therapy became more pronounced the longer the mice were followed. This suggests that the laser-stimulated reparative processes in the brain took some time to complete. Also, LLLT-treated mice showed a significant reduction in lesion size at 4 weeks compared to untreated TBI mice.

Scaffold/Neural Stem Cell Treatment for TBI

Researchers at the University of Pittsburgh, through an award from the PH/TBI Research Program, are evaluating the efficacy of a biodegradable, porous, and conductive scaffold on the long-term survival and integration of transplanted stem cells following TBI induced by cortical impact in rats. The researchers produced a new extracellular matrix scaffold derived from urinary bladder matrix for neural stem cell seeding and growth. They demonstrated that urinary bladder matrix gel injection following injury significantly improved motor function and reduced lesion volume; however, it did not result in a significant improvement in cognitive performance.

Multidrug Treatment of TBI

There are currently no drugs available to effectively treat TBI despite a growing need for neuroprotective interventions. Past studies have focused on single-drug therapies that have had little clinical success. PH/TBI Research Program-funded scientists at the State University of New York Downstate Medical Center are conducting a study to screen pairs of FDA-approved drugs for efficacy in a rat model of TBI to develop a multidrug regimen for the treatment of TBI. They initially established a set of neurobehavioral tasks that discriminates between mild and moderate TBI in rats. They are screening drugs, singly and in combination, by dosing the animals 1 hour after injury in the controlled cortical impact animal model of TBI. One week after injury, the researchers tested the drug combinations for synergy on the hierarchy of behavioral tests. They found that co-delivery of n-acetylcysteine with minocycline improved spaced learning suggesting a synergistic enhancement of memory. Examination of brain histology 2 weeks after injury suggested that minocycline plus n-acetylcysteine preserved white but not grey matter since lesion volume was unaffected, yet myelin loss was attenuated.

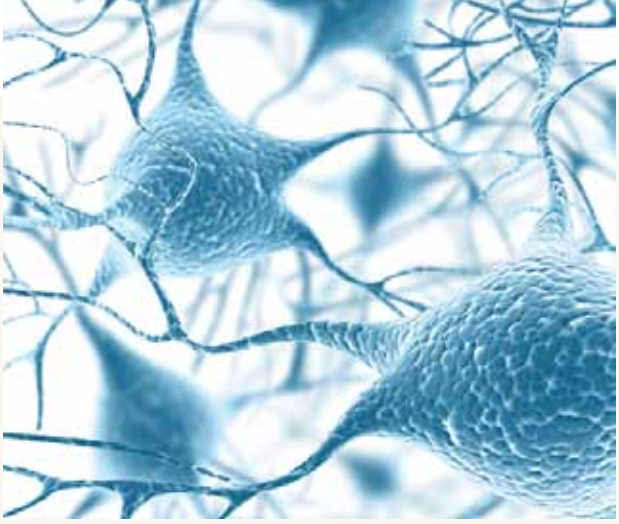
Small-Molecule Activators of the Trk Receptors Offer Neuroprotection Following TBI

Preclinical and clinical findings suggest neurotrophins as a promising therapy for TBI. However, their poor pharmacokinetic behavior and bioavailability at the desired targets make them poor candidates. Much effort has been devoted to the search for novel small-molecule activators that will mimic the desired neuroregenerative responses of neurotrophins. Researchers at the Veterans Medical Research Foundation of San Diego, with funding from the PH/TBI Research Program, are working to develop neuroprotective

drugs that will activate the Trk receptors to prevent neuronal cell death following TBI and improve cognitive function. To date, they have (1) identified the lead drug, 5E5, and 38 other promising compounds based on their ability to activate the TrkB receptor; (2) completed an in vivo evaluation of the neuroprotective effects of 5E5 utilizing two mouse models of neurodegeneration; and (3) tested 5E5 in a controlled cortical impact model of brain injury. The in vivo results indicated that treatment with 5E5 delayed the onset of cognitive impairments and improved the ability of the mice to learn spatial information when given before or after the onset of symptoms in both models of neurodegeneration. The drug also exerted a neuroprotective effect, reduced the magnitude of the brain injury as measured by a smaller contusion area, and improved motor skills in the cortical impact model of TBI.

Preclinical Evidence Supports Further Development of Amnion-Derived Multipotent Progenitor Cells for Brain Injury Treatment

Investigators at the Walter Reed Army Institute of Research with support from the PH/TBI Research Program have demonstrated beneficial outcomes



from transplanting amnion-derived multipotent progenitor (AMP) cells into brain-injured rats. Investigators showed that secreted factors from AMP cells can reduce neurite degeneration following damage to neurite cells grown in culture. When a collagen scaffold containing AMP cells was injected in brain-injured rats, viable cells began to fill the injury. Investigators discovered that the AMP cells did not differentiate into neurons, but endogenous astrocytes and neural progenitor cells migrated into the scaffolding created by the AMP/collagen matrix. Behaviorally, brain-injured rats that were treated with the AMP/collagen matrix were better able to maintain balance on a rotating rod test than injured rats only treated with collagen.

Reset – Regenerative Medicine

New Methods of Soft Tissue Reconstruction

AFIRM-funded scientists at the Cleveland Clinic Foundation have created a reinforced fascia-derived tissue for use in abdominal wall reconstruction. Reconstruction of the abdominal wall following trauma or traumatic sequelae is very challenging, and the outcomes are often unsatisfactory. The construct developed by these researchers offers a material with the necessary structural and mechanical properties to maintain a competent abdominal wall without the deformity and disability of an autologous donor site for the tissue. This technology will be studied in a large animal model in FY12. This application is an extension of research done on a material for rotator cuff repair, which is transitioning to private industry funding for clinical trials development and execution.

Engineered Muscle and Cartilage to Assist in Rehabilitation

AFIRM-funded researchers at Massachusetts General Hospital/Harvard University have made significant progress in defining a "living ear prosthesis" using the patient's own cartilage cells to develop an engineered structure that would be more patient friendly than any of the artificial prostheses used today. The laboratory has also achieved proof of concept for the de novo engineering of functional human muscle tissue, the first application being the restoration of movement in a damaged eyelid. This research addresses the significant problems encountered by warriors who have lost control of their eyelids and are unable to maintain the hydration of the cornea through regular blinking.

Patient's Own Stem/Progenitor Cells May Help Treat Compartment Syndrome Injury

Compartment syndrome involves increased pressure in a muscle compartment that can lead to muscle and nerve damage and can impair blood flow. Wake Forest University scientists, funded through the AFIRM, have been developing an approach to recruit a patient's own stem/progenitor cells to the site of compartment syndrome injury to increase the regenerative response. They are using biomaterials containing muscle-inducing factors that can be implanted within the injured muscle compartment. The researchers have now shown proof of principle in vitro and validated their method in a small animal model of tissue injury.

Skeletal Muscle Progenitor/Stem Cells May Improve Muscle Injury Recovery

AFIRM-funded scientists at USAISR are developing cell-based regenerative medical approaches to reduce the magnitude of injury, hasten healing, and improve the outcomes of wounded warfighters suffering from ischemic/reperfusion muscle injuries, which can be caused by tourniquet application, vascular trauma, or acute compartment syndrome. They have demonstrated improved muscle function in the short term following ischemic/reperfusion through the early injection of skeletal muscle progenitor/stem cells.

Evaluating Biomaterials for the Fabrication of Bone Regeneration Scaffolds

Cleveland Clinic researchers, funded through the AFIRM, completed a detailed competitive evaluation of new biomaterials for the fabrication and characterization of three polymer-based bone regeneration scaffolds. They down-selected scaffold materials in the canine femoral multidefect model. Among the materials tested to date, the porogen-leached, tyrosine-derived polycarbonate with beta tri-calcium phosphate performed best. The researchers also established a defined track record of historical performance standards that can be used to rapidly benchmark the performance of new or competing scaffold materials using this model.

Developing Functional Muscle Tissue for the Face

Blast injuries to unprotected craniofacial tissue cause severe damage to facial muscles such as the orbicularis oculi (eyelid). Researchers at Massachusetts General Hospital have been funded by the Deployment Related Medical Research Program to develop a generic physiological approach to engineer functional muscle tissue in a human-based platform using clinically relevant autologous cell sources. The researchers engineered three-dimensional muscle constructs called myooids and implanted them into the dorsal fat pads of nude mice. At 7 days post implantation, the myooids stained positive for the fast myosin heavy chain isoform, confirming that the muscle phenotype was preserved. In initial innervation (nerve supply) studies, myooids were implanted into the submandibular space of immunocompromised rodents. The hypoglossal or marginal mandibular motor nerve was transferred and secured to the implanted muscle. Nerve growth was observed in engineered muscles 4 weeks following nerve transfer. The researchers have also developed a model in which an engineered muscle is implanted into the thigh of an immunocompromised rat and innervated with the tibial nerve.

Bioprinting of Skin Cells Directly on Wounds

AFIRM-funded scientists at Wake Forest University are using inkjet technology to achieve the "printing" of skin onto an excised burn wound. They developed a portable skin printing device and achieved delivery of skin cells directly onto skin defects in a mouse model using the device. They isolated and expanded two types of skin cells from porcine skin and found that the cells remained viable when delivered through their device's printer nozzles. The printed cells participated in skin tissue formation and wound repair in the porcine excisional wound model. The researchers plan to design a bioprinter suitable for clinical application.

Bone Marrow-Derived Stem Cell Treatment for Compartment Syndrome

Researchers at the Oregon Medical Laser Center, funded through the AFIRM, are developing a bone marrow-derived stem cell treatment regimen for compartment syndrome injuries that is aimed at shifting the balance from cellular degeneration and scar tissue formation to the generation of physiologically active cells, resulting in improved muscle and nerve function. The treatment uses autologous (one's own) bone marrow-derived stem cells. The researchers also developed a method of tracking the cells after they are implanted in an animal and demonstrated robust cell engraftment up to 3 months post treatment. They completed a pilot study in Sinclair mini-swine and have treated 29/30 animals in a pivotal dose study. Their results to date suggest that adult bone marrow is a potential multipotent cell source for injured tissue repair.

Regrowing Blood Vessels in Traumatized Tissue

AFIRM-funded scientists at USAISR are using an individual's own adipose-derived stem cells (ASCs) and a biomaterial that mimics natural extracellular matrix as a strategy to regrow blood vessels into traumatized tissue. They found that ASCs inside the matrices were viable, proliferated, and formed microvessels. They delivered ASCs in a gel to a full-thickness excision wound in the rat and found enhanced growth of blood vessels compared to control gels lacking ASCs. The researchers plan to initiate studies in a porcine model and will use this model to develop a large total body surface area burn, which they predict will provide a stringent test for their product and for other AFIRM-related skin equivalent products.

Reset – Transplants

Reconstructive Transplantation Research

Composite tissue transplantation offers wounded warriors with severe disfigurement and dysfunction another option for restorative surgery over standard reconstructive treatments. Progress is being made in several AFIRM-funded research sites. Scientists at Brigham and Women's Hospital have successfully performed three facial transplantations. All three patients are experiencing return of sensation and motor function in the transplanted tissue. Researchers at the University of Pittsburgh Medical Center are using structural fat grafting to improve craniofacial appearance after trauma. This study is still in progress, and analyses of results are pending completion. Several subjects with

military affiliation, active or retired, have been treated. 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. At least six subjects have received hand transplantation although not all of these surgeries have been supported by DoD funding. One of these subjects is more than 10 years post surgery. Researchers at these institutions are also studying the mechanisms of tolerance induction to allogenic tissue grafts in animal models. These studies can potentially lead to minimization or elimination of immunosuppressive drug regimens currently required to prevent rejection of transplanted tissues.

Hand Transplants Requiring Less Immunosuppressive Therapy

Investigators at the JHU School of Medicine and the University of Pittsburgh, funded through the AFIRM, have developed a protocol for hand transplantation using a patient's own bone marrow with the addition of the immunosuppressive CTLA4Ig fusion protein. This protocol minimizes the amount of maintenance immunosuppressive therapy required following a transplant. Hand transplants on five patients have been completed to date. 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 hand therapy.

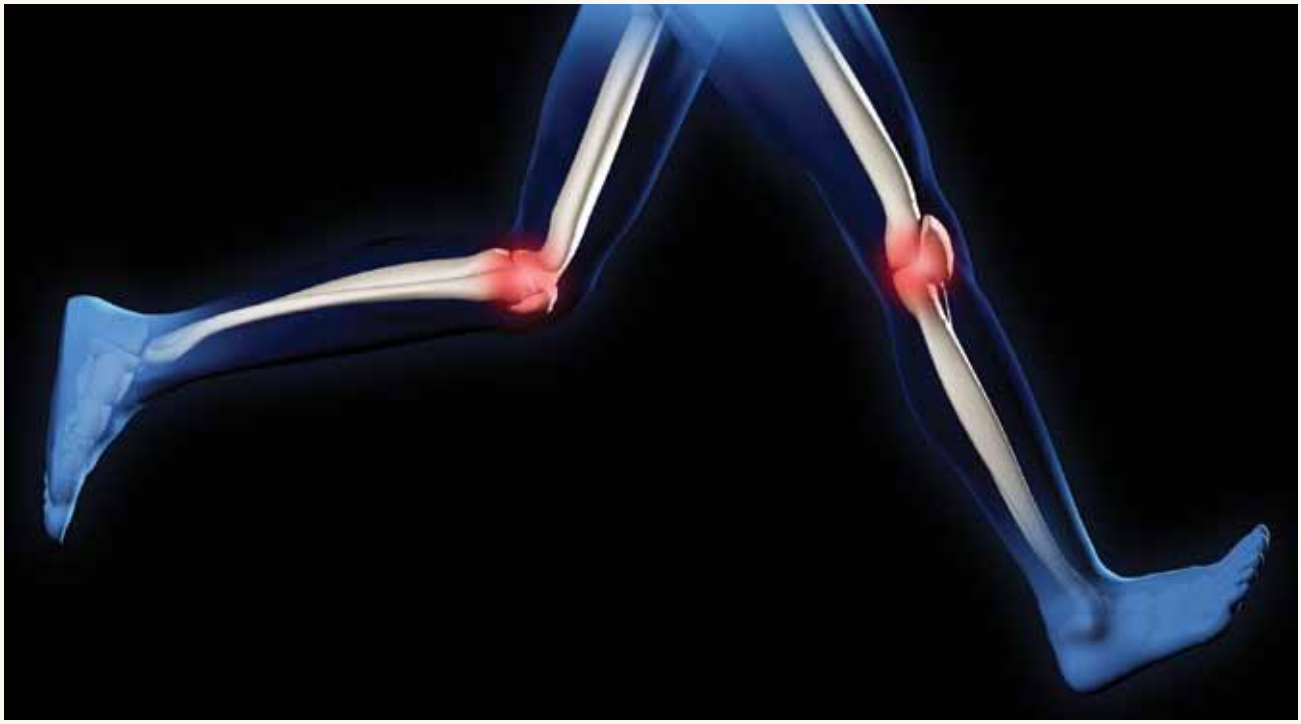
Reset – Rehabilitation

Development of a Self-Powered Prosthetic Knee

The two most significant issues that reduce mobility for lower limb amputees are pain and walking fatigue. While computer-controlled prosthetic devices can improve mobility for amputees, their energy expenditure remains higher than able-bodied persons. In an effort to reduce this increased energy expenditure, Deployment Related Medical Research Program-funded researchers at the University of Michigan have successfully launched the development of a self-powered prosthetic knee, two models of a prosthetic foot, and an instrumented device for recording daily activities of amputees walking with prostheses. The team has also been able to characterize the electromyographic signals that may lead to improved control of lower limb prostheses in future devices.

Wireless Sensor System for Accurate Real-Time Fitting of Lower Limb Prostheses

Deployment Related Medical Research Program-funded researchers at Michigan Technological University are developing a functional, wireless sensor system that ensures the proper fitting of a lower limb prosthetic by real-time monitoring of pressure distribution at the body–prosthesis interface. Utilizing Metglas®, a commercial magnetoelastic material, they were able to fashion a sensing layer with great sensitivity and repeatability into the desired shape and pattern.



Developing a Computer Simulation of the Knee to Aid in Rehabilitation

Computer modeling of knee mechanics can potentially be used to guide, evaluate, and predict the effect of rehabilitative interventions. Deployment Related Medical Research Program-funded researchers at the Rehabilitation Institute of Chicago are developing a state-of-the-art continuum knee model that can account for the coupled relationship between the patellofemoral and tibiofemoral joints of the knee, which is believed to contribute to the pathomechanics of many knee disorders. They acquired MRI data from six individuals and created an FE mesh for both the female and the male knee. To date, two knees have been fully meshed, and several secondary validation tests have been conducted. Simulations have been conducted using two main material models—isotropic Neo-Hookean and transversely isotropic. They have had success in the prediction of joint kinematics with the transversely isotropic model.

Vagus Nerve Stimulation Improves the Rehabilitation of Rats with TBI

Vagus nerve stimulation (VNS) is currently used as part of a treatment regimen for certain types of epilepsy and major depression, and researchers at Southern Illinois University are now investigating its use as a treatment for brain injury. Rats exposed to TBI and treated with VNS beginning within 2 weeks of the injury were able to recover motor function sooner and to a greater extent than animals exposed to the same injury but without VNS. In addition, coupling VNS treatment with rehabilitative training was shown to be superior to rehabilitative training alone. The researchers believe they have enough data to justify VNS testing in clinical trials.

Reset – Psychological Health

Studying the Effects of Multiple Concussions in Military Personnel

Concussions are common among U.S. military personnel serving in Iraq and Afghanistan, and evidence from civilian literature suggests that some aspects of neurocognitive function do not recover as quickly in those who have experienced multiple concussions. Some studies even suggest that a permanent reduction in cognitive performance can occur. Researchers at the NHRC

in San Diego, California, funded through the PH/TBI Research Program, completed and published a study that describes the effects of repeated concussions among U.S. military personnel and examines their subsequent health care utilization rates and services. This is one of the first studies of repeated concussion among military personnel in a combat-deployed setting. The researchers found that service members with a second concussive event during deployment utilized more health care resources and suffered greater mental health issues following deployment. Utilization rates for neurology and mental health services for repeat concussion casualties were higher than for those with a single blast-related concussive event. The study further revealed that the majority of concussive incidents were blast related. The median time between events was 40 days, with 20% experiencing a second concussive event within 2 weeks of the first, and 87% experiencing the second concussive event within 3 months.

Pituitary Hormone Therapy Shows Promise for mTBI Patients

Studies of civilian TBI have found evidence of chronic hypopituitarism in 30%–70% of cases. Hypopituitarism is associated with symptoms that resemble those of combat stress reaction or PTSD, including fatigue, anxiety, depression, irritability, insomnia, sexual dysfunction, cognitive deficiencies, and decreased quality of life. In a study funded by the PH/TBI Research Program and performed by the VA Puget Sound Health Care System, investigators measured pituitary and target-organ hormones in blood samples from Iraq/Afghanistan veterans with blast concussion mTBI to determine the frequency of pituitary dysfunction in this patient population. They found that 42% of participants with blast concussions had abnormal hormone levels. If symptoms characteristic of both post-traumatic hypopituitarism and PTSD can be linked to pituitary dysfunction, the participants may be amenable to treatment with hormone replacement. Routine screening for chronic hypopituitarism after blast concussion shows promise for appropriately directing diagnostic and therapeutic decisions that otherwise may remain unconsidered and for markedly facilitating recovery and rehabilitation.

Understanding the Enhanced Fear Response in mTBI Patients

mTBI results in cognitive and emotional dysfunction. However, because physically traumatic events typically occur in a highly emotional context, it is unknown whether TBI itself is a cause of augmented fear and anxiety. To investigate the potential neurobiological link between mTBI and PTSD, scientists from the University of California, Los Angeles have developed an animal model that combines the use of lateral fluid percussion injury with Pavlovian fear conditioning to reproduce PTSD after TBI. This model can be used to characterize the enhanced fear-based learning triggered by the injury. Investigators found that context and cued fear were significantly enhanced after injury when compared to sham surgery controls. These results suggest that mTBI predisposes the brain toward heightened fear learning during stressful post-injury events and provides a potential molecular mechanism by which this occurs. Furthermore, these data represent a novel rodent model that can help advance the neurobiological and therapeutic understanding of the comorbidity of PTSD and TBI.

Determining the Effects of Blast Versus PTSD on Brain Function and Structure

The clinical presentation of individuals with blast-related neural damage and post-traumatic psychopathology are markedly similar, making a clear description of the direct consequences of explosive blast complicated by the emotional and cognitive sequelae of psychological trauma. Researchers at the University of Minnesota and the Minnesota VA Medical Center have been funded by the PH/TBI Research Program to differentiate the effects of combat-related PTSD and blast-induced TBI in military personnel by using sophisticated measures of neural function and structure. Subjects are being recruited into one of four experimental groups: PTSD (PTSD, no blast exposure), blast (blast exposure, no PTSD), PTSD and blast, and control (neither PTSD nor blast). To date, clinical, MRI, and quantitative electroencephalogram (EEG) data have been collected on 112 warfighters who have returned from OIF/OEF deployment. Preliminary analyses of quantitative EEG data revealed diminished synchronization of activity across the frontal lobes of the brain in individuals with blast-related mTBI. The diminished EEG synchronization in subjects with blast-related mTBI was also associated with the lower structural integrity of white matter connections to the frontal lobes of the brain (fractional anisotropy as measured through diffusion tensor imaging).

Chapter 8
Way Forward

The Blast Injury Research PCO will continue to coordinate and expedite prevention, mitigation, and treatment strategies for blast-related injuries. A number of planned efforts and existing initiatives during the next few years will support this goal.

Research and Development

- Continue efforts to identify, prioritize, and resolve research gaps across the spectrum of blast injury research.
- Understand the linkage between blast exposure and later psychological trauma and effects.
- Promote research data sharing to expedite solutions to current problems.
- Focus on developing, validating, and transitioning to use biomedically relevant models of blast injury effects to support improvements in protection and treatment strategies.
- Transition new and updated blast injury protection standards to support improved vehicle and PPE designs.

Key Initiatives

JTAPIC Program

Continue to streamline and enhance joint service information sharing and collaboration for the analysis and prevention of injuries in combat. Work with international partners to develop similar capabilities for their militaries and sharing of information across partners.

MHS Blast Injury Prevention Standards Recommendation Process

Implement a reliable and robust process for identifying, assessing, and recommending injury models for use by materiel developers, the test and evaluation community, and policy makers. The PCO is committed to sponsoring two BIPSR reviews per

year. These reviews are intended to identify MHS BIPS for the EA to recommend to the ASD(HA) for approval and DoD-wide implementation.

Battlefield Exposure Sensor Data Analysis

Continue to collect and assess data from blast exposures to the head in the operational environment. Additionally, support the development and evaluation of improved and novel technologies for measuring and recording blast exposures.

Computational Modeling of mTBI

Establish an enterprise-based approach to achieve the goal of validated models of mTBI. The enterprise will consist of research CoEs, a national database/repository, and a Program Integrator. The enterprise will set the broad research agenda and prioritize specific research challenges, set a framework for the sharing of information and resources, and guide the effort so that it stays focused on the solution.

State-of-the-Science Meeting Series

The next State-of-the-Science meeting will focus on rehabilitation/restorative aspects of limb salvage. The meeting is scheduled for the third quarter of FY13. Topics for future State-of-the-Science meetings are being planned in coordination with the Joint Program Committee Chairs.

Coordination

- Continue to promote coordination and collaborative activities to improve blast injury prevention, mitigation, and treatment among the various scientific communities from biomedical research to protective equipment and vehicle developers.
- Promote linkages and information sharing among DoD, federal, academic, and industry programs and expertise to solve difficult blast injury problems.
- Expand endeavors to synchronize efforts, standards, and capabilities with international partners.

Appendix A
Acronym List

5P	Five Power
AAAP	Anti-Armor Analysis Program
AFES	Automatic Fire Extinguishing System
AFIRM	Armed Forces Institute of Regenerative Medicine
AFMES	Armed Forces Medical Examiner System
AIS	Abbreviated Injury Scale
AMP	Amnion-Derived Multipotent Progenitor
ARL	Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics, and Technology
ASBREM	Armed Services Biomedical Research Evaluation and Management
ASC	Adipose-Derived Stem Cell
ASD(HA)	Assistant Secretary of Defense for Health Affairs
ASHA	Aluminum Silicate-Based Hemostatic Agent
BIPS	Blast Injury Prevention Standards
BIPSR	Blast Injury Prevention Standards Recommendation
BOP	Blast Overpressure
bTBI	Blast Traumatic Brain Injury
BVFT	Battlefield Vehicle Forensics Team
CoE	Center of Excellence
CSI	Congressional Special Interest
CTTSO	Combating Terrorism Technology Support Office
DARPA	Defense Advanced Research Projects Agency
DCoE	Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury
DoD	Department of Defense
DoDD	DoD Directive
DOT&E	Director, Operational Test and Evaluation
EA	Executive Agent
EACE	Traumatic Extremity Injuries and Amputation Center of Excellence
EEG	Electroencephalogram
FAST	Field Assistance in Science and Technology
FDA	U.S. Food and Drug Administration
FE	Finite Element
FINSS	Fully Integrated Neuropsychiatric Support System
FY	Fiscal Year
Gen II HMSS	Generation II Helmet-Mounted Sensor System
GFAP	Glial Fibrillary Acidic Protein
HCE	Hearing Center of Excellence
HET	Heavy Equipment Transporter
HFM	Human Factors and Medicine
HIT	Human Injury and Treatment
HSHM	Human Surrogate Head Model
IED	Improvised Explosive Device
IIPT	Integrating Integrated Product Team
JHU/APL	Johns Hopkins University Applied Physics Laboratory
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat
KIA	Killed In Action
LFT&E	Live-Fire Test and Evaluation
LLLT	Low-Level Light Therapy

MEMS	MicroElectroMechanical Systems
MHS	Military Health System
MRI	Magnetic Resonance Imaging
mTBI	Mild Traumatic Brain Injury
NATO	North Atlantic Treaty Organization
NF-H	Neurofilament Heavy Chain
NGIC	National Ground Intelligence Center
NHRC	Naval Health Research Center
NIH	National Institutes of Health
NSRDEC	Natick Soldier Research, Development, and Engineering Center
OASD(HA)	Office of the Assistant Secretary of Defense for Health Affairs
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OSD	Office of the Secretary of Defense
PB	President's Budget
PCO	Program Coordinating Office
PEO	Program Executive Office
PH/TBI	Psychological Health and Traumatic Brain Injury
PM	Program Manager
PMO	Program Management Office
PM ICE	Program Manager Infantry Combat Equipment
PM SPE	Program Manager Soldier Protective Equipment
POG	Protective Outer Garment
PPE	Personal Protective Equipment
PTB	Photochemical Tissue Bonding
PTSD	Post-Traumatic Stress Disorder
PUG	Protective Under Garment
RFI	Request for Information
S100B	S100 Calcium-Binding Protein B
SBDP 150	Spectrin Breakdown Product 150
SLAD	Survivability/Lethality Analysis Directorate
SME	Subject Matter Expert
SNR(A)	Senior National Representatives Army
TARDEC	U.S. Army Tank Automotive Research, Development, and Engineering Center
TBI	Traumatic Brain Injury
TGAS	Toxic Gas Assessment Software
TRADOC	Training and Doctrine Command
TRMC	Test Resource Management Center
TSWG	Technical Support Working Group
TTP	Tactic, Technique, and Procedure
TWVS	Tactical Wheeled Vehicle Survivability
UBB	Under-Body Blast
UBBRP	Under-Body Blast Research Program
UCHL1	Ubiquitin Carboxy-Terminal Hydrolase L1
USAARL	U.S. Army Aeromedical Research Laboratory
USAISR	U.S. Army Institute of Surgical Research
USAMRMC	U.S. Army Medical Research and Materiel Command
USUHS	Uniformed Services University of the Health Sciences
VA	Department of Veterans Affairs
VAID	Visual Anatomical Injury Descriptor
VCSA	Vice Chief of Staff of the Army
VNS	Vagus Nerve Stimulation
VV&A	Verification, Validation, and Accreditation
WIA	Wounded In Action
WIAMan	Warrior Injury Assessment Manikin

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. EFFECTIVE DATE

This Directive is effective immediately.

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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