DEPARTMENT OF DEFENSE

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

FY09 ANNUAL REPORT

to the Executive Agent

DoD Blast Injury Research Program Coordinating Office

EXECUTIVE SUMMARY

The Department of Defense (DoD) has made significant progress in coordinating and advancing medical research programs focused on preventing, mitigating, and treating blast-related injuries. Numerous collaborative efforts with other departments and agencies of the federal government and with other countries have enabled the Department to optimize scientific growth and productivity in this area, as well as resource sharing. The Department's efforts to disseminate findings on the prevention, diagnosis, and treatment of blast injuries and on the rehabilitation of blast-injured Service members through civilian and military research and medical communities have resulted in significant improvements in the way blast injuries are prevented and in the way we care for blast-injured Service members.

This Report to the Executive Agent highlights the activities undertaken in FY09 by the Blast Injury Research Program Coordinating Office (PCO), the Joint Trauma Analysis and Prevention of Injury in Combat Program Management Office (PMO), 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, analyses of DoD-wide blast injury research programming and budget data, 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 research accomplishments described in this report:

- Researchers at the University of Alabama, Birmingham are assessing whether the intravenous administration of high dose, soluble estrogen will decrease the damage of TBI from blast wave-induced injury
- Investigators at Washington University are looking into the diagnosis of blast-induced TBI using advanced MRI techniques
- The Military Amputee Research Program is developing a prosthetic knee that allows the user to have the capability of walking, running, and climbing and offers the potential of replacing up to six separate lower limb prostheses with one device

Among the key initiatives described in this report:

- A process established in collaboration with the Johns Hopkins University Applied Physics Laboratory for identifying and independently assessing blast injury prediction tools for implementation in blast injury prevention standards that guide the design of effective protection systems

EXECUTIVE SUMMARY

- The International State-of-the-Science Meeting Series that brings together the world's leading blast injury researchers to assess the scientific community's current understanding of key blast injury topics and to identify knowledge gaps to focus future research investments

- The newly formed DoD Expert Panel on Computational Modeling of Non-Impact, Blast-Induced mTBI that is providing a venue where the world's leading computational modeling experts are working collaboratively to close a major knowledge gap in the DoD Blast Injury Research Program

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 research is managed in a coordinated manner. This was the intent of Congress when it directed the Secretary of Defense to establish a coordinated DoD blast injury research program.

FOREWORD FROM THE DIRECTOR

Blast-related injuries continue to dominate the spectrum of injuries sustained by our Nation's Warfighters in current conflicts and are likely to play a major role in future conflicts. Along with advances in blast protection equipment has come a wide array of devastating but survivable blast injuries that would have been lethal only a few short years ago. The effective prevention, mitigation, and treatment of these injuries present many significant challenges for the medical research community.

From its inception in 2007, the DoD Blast Injury Research PCO has recognized that only a coordinated medical research effort involving the DoD, other federal agencies, academia, industry, and international partners can solve these tough blast injury research challenges. This report summarizes the fiscal year 2009 (FY09) achievements of this coordinated medical research effort as reported by the performing organizations. These achievements span the range of blast injury research issues within the broad framework of prevention, acute treatment, and reset and include diverse scientific areas ranging from the mathematical modeling of blast-related brain injuries to combat trauma care and the emerging field of regenerative medicine.

The PCO continued its emphasis in FY09 on identifying blast injury research knowledge gaps, actively participating on research planning committees, facilitating collaboration among medical researchers, establishing collaborative relationships between the medical research and protection equipment development communities, and fostering an open exchange of blast injury research information that breaks down historical communication barriers to advance the state of the science. This continued emphasis is highlighted by a wide range of initiatives that include the establishment of the International State-of-the-Science Meeting Series, the formation of an international expert panel on mathematical modeling of blast-related brain injuries, and the implementation of an independent process for evaluating blast injury prediction tools for blast injury prevention standards.

I have the privilege of working with a vast network of dedicated medical research professionals who are committed to solving these difficult blast injury challenges on behalf of our Nation's most treasured resource: the selfless men and women of our Armed Forces. It is my pleasure to present the achievements of these professionals in this FY09 Report to the Executive Agent for 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

I can tell you, from my perspective, the signature weapon of this conflict is blast, and blast is a potentially devastating weapon which can burn, can result in amputation of limbs, that can result in loss of eyesight and hearing, that can damage brains and obviously, as we're all concerned, can lead, because of the context of the conflict for the combatant, to many post-traumatic stress results.

LTG Eric Schoomaker, Commander, USAMEDCOM, April 17, 2008

Current operations in Afghanistan and Iraq, worldwide terrorist bombings, the advent of novel explosives, and the growing use of innovative explosive devices have resulted in overwhelming blast-related casualties. In 2006, Congress directed the Office of the Secretary of Defense to designate an Executive Agent (EA) to coordinate and manage 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, DoD issued a 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, assigned the responsibilities governing coordination and management of the medical research for prevention, mitigation, and treatment of blast-related injuries, and directed 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 (Acquisition, Logistics, and Technology) [ASA(ALT)], and the ASA(ALT) delegated authority and assigned program responsibility to the Commander, U.S. Army Medical Command (USAMEDCOM).

The Blast Injury Research Program Coordinating Office (PCO) was established at the U.S. Army Medical Research and Materiel Command (USAMRMC), Fort Detrick 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 Commander, USAMRMC and USAMEDCOM 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.

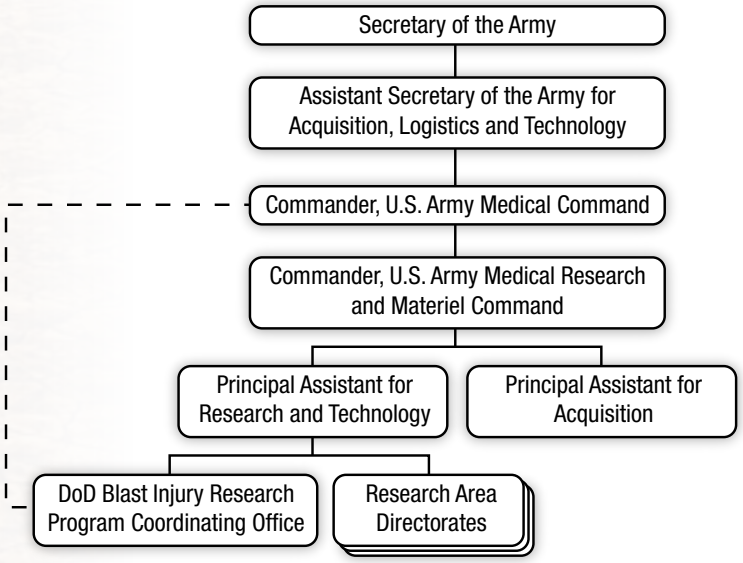


Figure 1-1. Relationship of the DoD Blast Injury Research Program Coordinating Office to the DoD EA

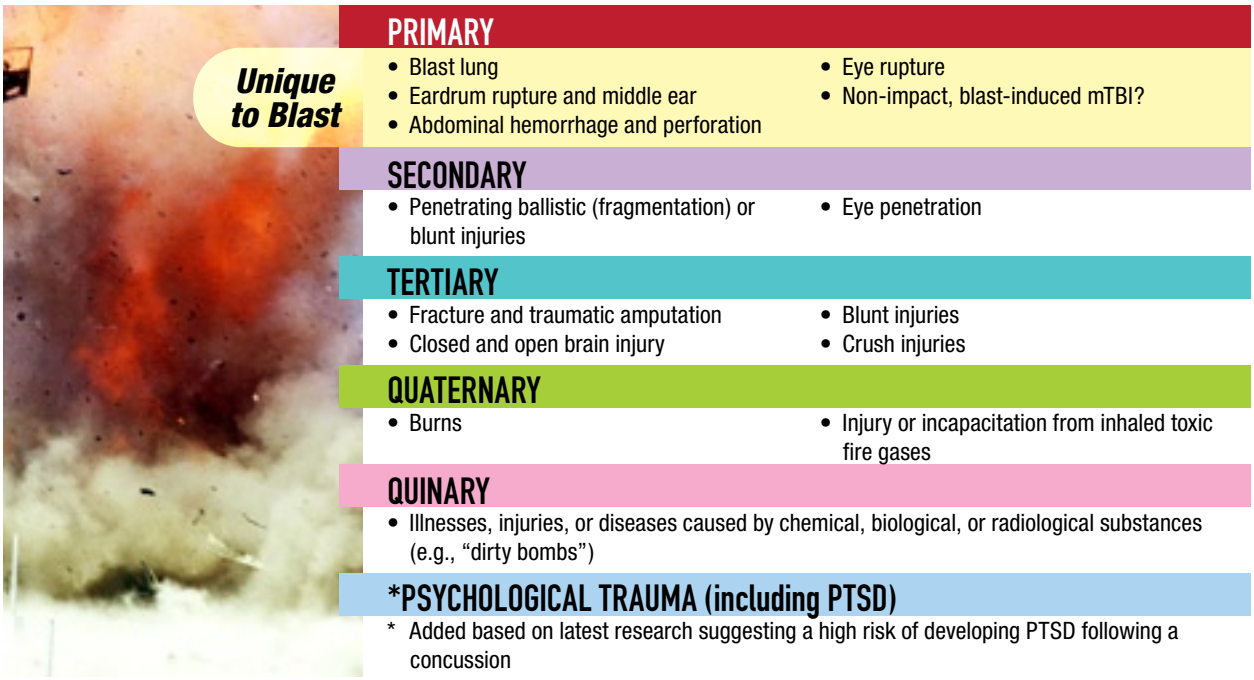


Figure 1-2. Types of Blast Injuries per DoDD 6025.21E

The term "blast injury" creates much confusion. Simply stated, "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.

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 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 or a fall. These are known as tertiary blast injuries. Quaternary blast injuries are the result of other explosive products, such as heat, light, and toxic 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 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 Topics by Program Areas

Key Research Topics

The Blast Injury Research Program is focusing on filling 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.

DoD Blast Injury Research Program Coordinating Office

Chapter 2

DOD BLAST INJURY RESEARCH PROGRAM COORDINATING OFFICE

Mission: 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 DoD medical research community has been conducting medical research on blast-related injuries for decades. These decades of research have produced tremendous advances in battlefield medicine that are responsible for preventing blast injuries and saving the lives of blast-injured Service members on today's battlefields. 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 DoD Blast Injury Research Program (Figure 2-1) 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.

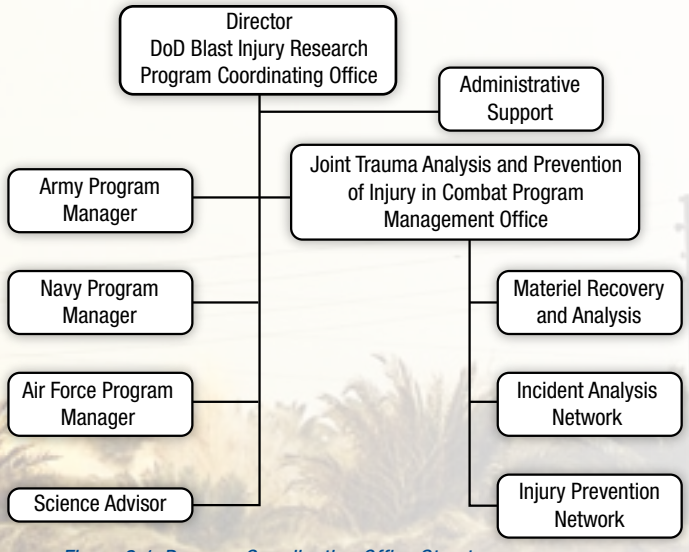


Figure 2-1. Program Coordinating Office Structure

Since its inception, the PCO has made significant progress in establishing and managing a coordinated Blast Injury Research Program. Examples of successes include:

1. **Identification of Blast Injury Research Knowledge Gaps.** The PCO held the first DoD blast injury research planning meeting in July 2006, during which representatives from the DoD, federal agencies, academic institutions, and industry assessed the state of the science and identified knowledge gaps in blast injury research. These gaps, detailed in the January 2008 Annual Report to Congress, were used to develop a prioritized list of program funding requirements and prepare program announcements and solicitations for research proposals.

2. **Development of DoD Blast Injury Research Program Management Taxonomy.** A new research program management taxonomy was developed to support the three main research topics as described earlier. Subtopics within each of the major topic areas address specific research thrust areas as shown in Table 2-1.

Table 2-1. Major Topic Areas

DoD Blast Injury Research Program Management Taxonomy
Injury Prevention
• Injury Surveillance
• Individual Resilience Training
• Protection Standards
• Personalized Medicine
Acute Treatment
• Medical Treatment Outcomes Analysis
• Health Care Provider Training
• Wound Care
• Diagnostics
Reset
• Return-to-Duty Standards
• Individual Retraining
• Advanced Prosthetics
• Regenerative Medicine

The PCO uses these major categories and thrust areas to promote a comprehensive and balanced portfolio of blast injury research and related projects designed to prevent, treat, and mitigate blast-related injuries.

3. **Strengthen and Expand Collaborations Between the Medical Research Community and the 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 has continued to strengthen and expand this important relationship as illustrated in the following activities:

   - Served as the medical lead for the Vice Chief of Staff of the Army's (VCSA's) helmet-mounted sensor system fielding initiative
   - Shaped and focused the Combating Terrorism Technology Support Office/ Technical Support Working Group (TSWG) blast injury research Broad Agency Announcement (BAA) by serving as a voting member on the TSWG Human Lethality Integrating Integrated Product Team (IIPT).

4. **Active Participation on Various Committees.** The PCO staff participates as voting members on numerous research program planning and management committees to ensure blast injury knowledge gaps are addressed in DoD medical research programs. These include:

   - Joint Program Committees (JPCs): The JPCs, with membership from the Component services, Department of Veterans Affairs (VA), National Institutes of Health (NIH), 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 for major DoD medical research programs, such as the Deployment Related Medical Research Program (DRMRP), that include blast injury research topics.
   - Joint Technology Coordinating Groups (JTCGs) are organized under the ASBREM committee. The JTCGs 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.
   - IIPTs were created to implement a teaming approach to manage biomedical science and technology at the USAMRMC. IIPT membership consists of personnel from the combat development community and subject matter experts from DoD, academia, and other organizations. The IIPTs are responsible for advising the Research Area Directors of the USAMRMC on the current focus and future direction

of their medical research programs that include key blast injury research topics.

5. 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.

Significant international events include:

- Hosted a delegation from the Singapore Defense Medical and Environmental Research Institute of the Singapore National Defence Research and Development Organization National Laboratories. Meeting participants identified opportunities for the United States and Singapore to collaborate on blast-induced brain injury computational modeling projects.

- Participated in the fifth meeting of the NATO Research and Technology Organization's Technical Team [Human Factors and Medicine (HFM)]-148 entitled "Criteria and Test Methodologies for Injury Assessment of Vehicle Occupants Threatened by Landmines and/or Improvised Explosive Devices (IEDs)."

- Participated in a workshop entitled "Non-Penetrating Wounds Caused by Ballistic Impacts and Blast." The DGA (The French Defense Procurement Agency) and SSA (The French Defense Medical Service) sponsored this workshop.

6. PCO in the News

- "Mild Traumatic Brain Injury Research" story in the Army's Stand-To, 23 June 2009 (http://www.army.mil/standto/archive/2009/06/23/). The article summarized the International State-of-the-Science Meeting on Non-Impact, Blast-Induced Mild Traumatic Brain Injury (mTBI).

- "Helmet Sensors Providing Data That May Decrease Brain Injury" story in the Defense Technology News—By U.S. Army, September 4, 2009 (http://www.defencetalk.com/helmet-sensors-providing-data-that-may-decrease-brain-injury-21594/).

  The article addressed the fielding of helmet-mounted sensors to deployed Soldiers and Marines to help determine what constitutes an injury-causing impact and the value of sensor data in providing the Army with insights into future helmet design.

USA TODAY

News

Military used pigs in blasts to test armor

By Tom Vanden Brook, USA TODAY

WASHINGTON — Military researchers have dressed live pigs in body armor and strapped them into Humvee simulators that were then blown up with explosives to study the link between roadside bomb blasts and brain injury.

For an 11-month period that ended in December, researchers subjected pigs and rats to about 200 blasts, according to Pentagon documents and interviews. The explosions have ranged in intensity, wounding some of the pigs and killing others. Roadside bombs are the top killer of U.S. troops in Iraq and Afghanistan.

MILITARY: Studies shed light on brain injuries from blasts

The research on pigs has determined that body armor does not worsen brain injury, said Jan Walker, a spokeswoman for the Defense Advanced Research Projects Agency, or DARPA, which conducted the study. The military feared body armor would deflect the force of blasts toward the head and increase the risk of brain injury.

The research also shows that body armor protects troops' lungs and is critical to surviving blasts.

- "Military used pigs in blasts to test armor" story in *USA Today*, April 6, 2009 (http://www.usatoday.com/news/military/2009-04-06-pigs_N.htm).

  The primary focus of this interview was the use of animals and post-mortem human subjects in blast injury research. The PCO explained the Army's practice of formally reviewing medical research involving human or animal subjects ahead of time to ensure full compliance with regulatory requirements for the appropriate and ethical use of research subjects.

7. Significant Meetings

- Met with representatives from the University of Nebraska-Lincoln, the Army Research Office, and USAMRMC to discuss the newly established Center for Trauma Mechanics study of TBI resulting from IED blasts.

- Discussed head injury modeling work and explored opportunities for future collaboration with representatives from the National Highway Traffic Safety Administration (NHTSA).

- Identified specific research questions and data requirements to meet the Chairman of the Joint Chiefs of Staff's (CJCS) intent with representatives from the Office of the CJCS, VCSA, Defense Advanced Research Projects Agency (DARPA), the Defense Centers of Excellence (DCoE) for Psychological Health and Traumatic Brain Injury (PH/TBI), the Uniformed Services University of the Health Sciences (USUHS), Program Manager (PM) Soldier, USAMRMC, Office of the USAF Surgeon General, and Office of the USAF Air Combat Command Surgeon.

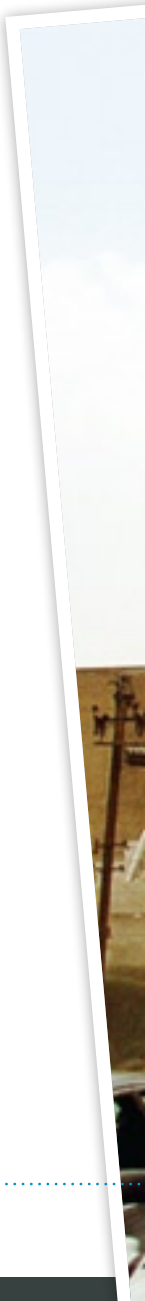
- Reviewed and prioritized FY10 BAA project requirements for the Combating Terrorism Technical Support Office (CTTSO)/TSWG Blast Effects & Mitigation (BX) Subgroup.

- Assessed existing surrogate human heads, or "headforms," for use in measuring responses to blast and impact being explored by the Head Blast Test Surrogate Project sponsored by the CTTSO/TSWG.

- Explored opportunities for interdisciplinary biomedical research with the Oak Ridge National Laboratory's Biomedical Science and Engineering Center in the following areas: (1) Biomedical Informatics (the intersection of computer science and medicine; i.e., data analytics, three-dimensional [3-D] visualization, user interfaces, data fusion, and multimodal integration), (2) Modeling and Simulation (visualization, organ models, mathematical, mechanistic and statistical modeling of biomedical problems), and (3) Measurement Science and Imaging Techniques (diagnostic tools and devices, biomarkers and biosensors, advanced imaging technologies, and visualization techniques).

- Assisted the DCoE for PH/TBI in development of common data elements and consensus on definitions, metrics, instrumentation, and outcomes so that comparisons can be made across studies.

- Facilitated the development of a Body Armor Blunt Trauma Assessment (BABTA) test device for the Army Research Laboratory (ARL), Survivability/Lethality Analysis Directorate (SLAD).



- Identified opportunities for the Navy Live Fire Test and Evaluation Program to leverage existing USAMRMC blast injury research tools that will eliminate the need for new research programs.

- Arranged a collaborative project with Wayne State University (WSU) to evaluate the BABTA performance testing method using actual case data from a behind armor blunt trauma injury involving a British police officer.

- Advised a panel of the Committee on Toxicology, Board on Environmental Studies and Toxicology, National Research Council, to consider the USAMRMC Toxic Gas Assessment Software (TGAS) as an assessment method for occupational exposures to low-level combined gases.

Chapter 3

JOINT TRAUMA ANALYSIS AND PREVENTION OF INJURY IN COMBAT PROGRAM

The JTAPIC Partners Provide Jointly Identified Solutions That Enhance Warfighter Survivability

A key responsibility of the DoD EA is to support the joint collection, analysis, and sharing of information related to the efficacy of theater personal and crew protection systems. The JTAPIC Program was established to fulfill this EA responsibility.

Prior to JTAPIC, military organizations had focused on improving Warfighter survivability from their individual perspectives. The medical community focused on battlefield medicine and increasing Soldier survivability by using the best medical and treatment modalities available. The Individual Body Armor testers 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 specific information on the operational context or injuries to the Warfighter. When a new modification to a vehicle was fielded in Operation Iraqi Freedom (OIF), there was no formal process to provide the Vehicle Developers with interpretive medical information regarding combat injuries. Likewise, for the medical community, there was no formal process for providing specific medical injury data to nonmedical users such as the combatant commander, materiel developers, and requirements generators at the Centers and Schools.

To streamline and enhance Joint Services information sharing and collaboration for the analysis and prevention of injuries in combat, JTAPIC established a partnership (Table 3-1) among the intelligence, materiel, and medical communities to share information for the prevention and mitigation of traumatic injuries in combat using common standards to ensure its validity and ensure that the information could be used in an appropriate manner.

Figure 3-1. MG James Gilman Presents Heavy Brigade Combat Team Award to the JTAPIC PMO Management Team, LTC Dick and Mr. Uscilowicz

Table 3-1. JTAPIC Partnership

JTAPIC Partners	
• Marine Corps Systems Command	• U.S. Army Institute of Surgical Research
• Naval Health Research Center	• U.S Army National Ground Intelligence Center
• Office of the Armed Forces Medical Examiner	• U.S Army PEO Soldier, Project Manager Soldier Equipment
• U.S. Air Force, Office of the Surgeon General	• U.S. Army Research Laboratory, Survivability/Lethality Analysis Directorate
• U.S. Army Aeromedical Research Laboratory	
• U.S. Army Infantry Center & School	

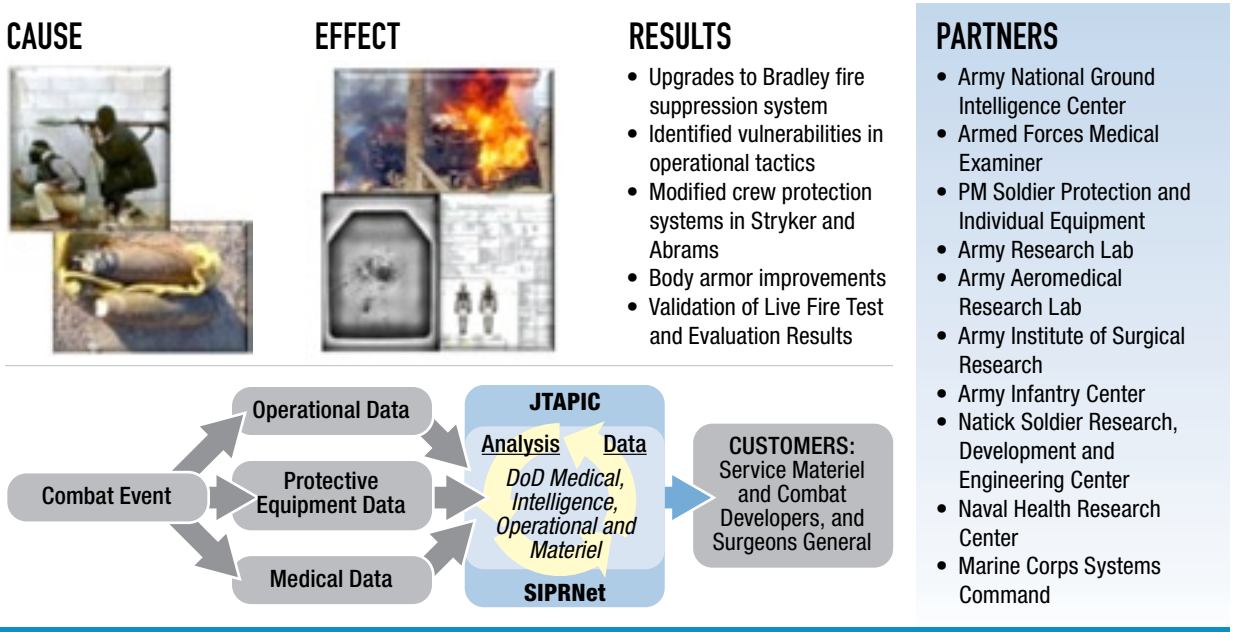


Figure 3-2. THE JTAPIC Process

From the beginning, the JTAPIC Program has been able to analyze and improve the understanding of our vulnerabilities to threats and enable the development of improved tactics, techniques, and procedures (TTP) and materiel solutions that will prevent or mitigate blast-related injuries. The program has received personal endorsements from the Commanding Generals of the U.S. Army Materiel Command, USAMEDCOM, and U.S. Army PEO Soldier. The JTAPIC Program has also been recognized as an approved Army Enduring Capability by VCSA via the Army Requirements Oversight Council process.

The JTAPIC Program was recognized by the PM Heavy Brigade Combat Team (HBCT) for providing required medical analysis data from combat incidents in theater. The data were vital to the ongoing modernization efforts for all HBCT platforms and will ensure that current and future generations of these platforms, and the Soldiers who depend on them, will be the best protected vehicles the Army can provide.

As shown in Figure 3-2, the JTAPIC Program is a partnership among the intelligence, operational, materiel, and medical communities with the common goal of collecting, integrating, and analyzing injury and operational data.

The JTAPIC partnership provides relevant information to its customers by having the appropriate service component subject matter experts work together to analyze data "in context."

In summary, to adequately analyze a combat event, JTAPIC gathers information from disparate sources with varying levels of classification and access to link 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. Critical capability gaps that JTAPIC has had to address include data collection and standardization, materiel recovery and analysis, data sharing and integration, and the timeliness and responsiveness of comprehensive analyses. Three key components of the JTAPIC are:

- **Materiel Recovery and Analysis**
  Materiel recovery and analysis component is a combined effort by Project Manager, Soldier Protection and Individual Equipment (PM SPIE), the Office of the Armed Forces Medical Examiner, and ARL to provide in-theater collection of damaged PPE (individual helmet and body armor) from WIA Service members and identification and analysis of foreign bodies (fragments) removed from KIA Service members during

- PPE collected, analyzed, and archived from ~1300 KIA cases and ~90 WIA cases
- PPE analyses drive PPE performance requirements and design changes for enhanced Warfighter survivability

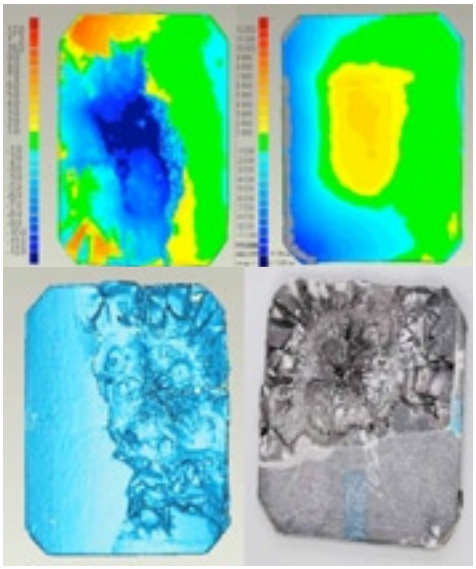


Figure 3-3. Incident Analysis - PPE and Materiel

post-mortem examination (Figure 3-3). Select PPE is analyzed for damage and performance, and retrieved fragment material properties are characterized. Fragment analysis data (Figure 3-4) can provide clues to the threat weapons involved in an incident, and modeling by ARL can then provide kinetic energy data that are useful to PPE and armor developers.

- **Incident Analysis Network**
  The Incident Analysis Network (IAN) generates detailed forensic crosswalks of combat incidents that tie together key information from several disparate sources related to a specific combat event. The U.S. Army National Ground Intelligence Center Anti-Armor Analysis Program provides operations and intelligence data, the Office of the Armed Forces Medical Examiner (OAFME) provides information on KIA Service members, JTAPIC provides information on WIA Service members, ARL provides analysis on any fragments collected from the incident and models the event, and PM SPIE provides analysis of the PPE involved in the incident. A multi-community analysis of the crosswalk provides the "so what" take-home message.

INCIDENT:

- Patrol hit by roadside IED
- Unit dismounted and secured area IAW SOP
- Dismounted Soldiers attacked by secondary device

ANALYSES:

Combined medical and engineering review of equipment and IED weapons effects

Element	Estimated Weight %	Estimated Atomic %
Carbon	6.94	27.81
Oxygen	0.77	2.31
Copper	92.29	69.88

FRAGMENT ANALYSIS

Outcome: Change in unit TTPs

Figure 3-4. Fragment Analysis - Secondary Attack (UNCLASSIFIED) Example for Illustration Only

INCIDENT:

- Patrol hit by buried IED
- Command wire initiation
- No hull breach
- 2 crew KIA/1 crew WIA

ANALYSES COORDINATED BY JTAPIC PROGRAM MANAGEMENT OFFICE:

- OAFME cause of death(s)
- JTTS/NHRC analyze the WIA data for injury trends
- NGIC identifies threat
- ARL looks for survivability solutions

Outcome: TTP on use of seat restraints, materiel solutions, threat identification

Figure 3-5. Incident Analysis - Underbelly Attack (UNCLASSIFIED), Example for Illustration Only

JTAPIC customers use these forensic crosswalks to guide survivability models and analyses and support vehicle/equipment development and milestone decisions (Figure 3-5).

- **Injury Prevention Analysis Network**
  The Injury Prevention Analysis Network (IPAN) provides actionable medical analysis on both a push-and-pull basis. The push system is based on data collected and information generated internally by JTAPIC partners that can be provided to its customers without a formal request. Customer requests for information (RFI) drive the pull system. The RFI process permits JTAPIC's customers to submit questions or requests to support and guide decisions. When a customer submits an RFI, JTAPIC works with its partners to collect and analyze the required data and provide a response in a timely manner.

The JTAPIC Program has already made a difference in the way we protect our Warfighters from blast-related injuries. The materiel recovery and analysis component combined with the IAN to confirm the presence of prominent threat weapons of interest to the intelligence community. The IPAN used incident, injury, and virtual autopsy data to identify potential vulnerabilities in operational procedures and rapidly conveyed those vulnerabilities to commanders in theater. The IAN provided actionable information to combat vehicle Project Managers that led to the modification of vehicle equipment to prevent or mitigate blast-related injuries. The program is currently analyzing performance data related to specific modifications to the up-armored, high-mobility, multipurpose wheeled vehicles to determine the effectiveness of those modifications. To date, the JTAPIC Program has processed approximately 171 RFIs from various customers throughout the DoD.

JTAPIC Key Initiatives

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

- **PPE Analysis Leads to Improved Armor**
  The JTAPIC Program Management Office (PMO) established a process in coordination with Product Manager - Soldier Protective Equipment (PM SPE) for collecting and analyzing damaged PPE, such as body armor and combat helmets, to provide PPE develop-

ers with the information needed to develop enhanced protection systems. These efforts resulted in the development of injury-based standards for PPE improvements and contributed to the development of the enhanced small arms protective inserts, enhanced-side ballistic inserts, and the improved outer tactical vest.

- **Streamlining Data Flow**
  The JTAPIC PMO is working with the JTAPIC partners to streamline the analyses processes and the flow of information from the partners to customers. The objective is to use the existing framework of the JTAPIC partnership to coordinate joint analyses of data by the partners, including the analyses of medical data by the medical partners, and to enhance the flow of information among partners from the RFI input to a coordinated analysis output. Each partner has specific data sources that they analyze and interpret using their own unique knowledge and skills.

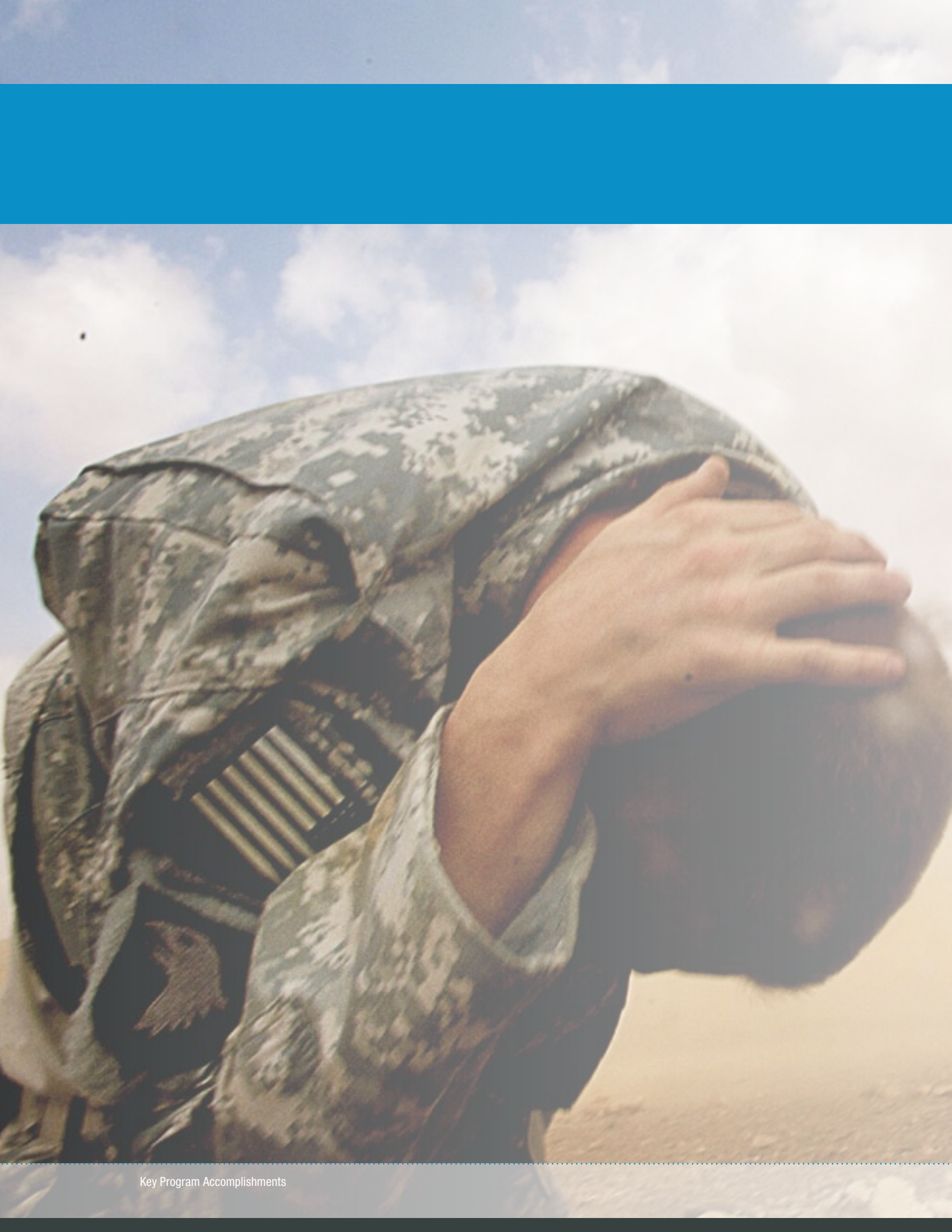
  JTAPIC and the Johns Hopkins University Applied Physics Laboratory (JHU/APL), under a University Affiliated Research Center partnership, have developed a Technical Evaluation Plan for an automated JTAPIC Data Management System (JDMS) that promises to significantly improve the flow of information among the JTAPIC partners and customers. Sponsorship and senior leadership acceleration of the JDMS will enable JTAPIC to meet internal and external requirements.

- **Ensuring the Long-Term Responsiveness and Stability**
  The JTAPIC PMO has taken action to obtain Program funding in the Army Program Objective Memorandum (POM). Briefing to the Army G-8 during the FY12-17 POM process resulted in a decision to continue funding JTAPIC in FY12 through Overseas Contingency Operations (OCO, MDEP VRIQ) and for inclusion in the President's Budget Review FY13-17 submission as part of the Base Program for future years resourcing and programming.

- **Near-Real Time Analysis of Combat Incident Data Confirms Presence of Threat Weapons of Interest**
  The JTAPIC PMO and its partners established a standardized near-real time process for collecting and analyzing combat incident data across multiple communities to provide direct feedback to commanders in theater for improving TTP.

- **JTAPIC Partners Influence Modifications to Vehicle Equipment and Protection Systems**
  The JTAPIC partnership provided actionable information to combat vehicle PMs, which led to modifications and/or upgrades to vehicle equipment and protection systems, such as seat design, blast mitigating armor, and fire suppression system.

- **Defining and Linking Casualty Injury Profiles to Significant Tactical Events**
  Naval Health Research Center (NHRC), a JTAPIC partner, provided injury profiles of 1,429 injured U.S. Service members including: 619 for attacks against individual dismounted personnel, 278 for Mine Resistant Ambush Protected (MRAP) vehicles, 224 for Stryker vehicles, 173 for Bradley fighting vehicles, 81 for armored security vehicles, and 54 for miscellaneous attacks against other U.S. assets. The injury profiles consist of injury descriptions using International Classification of Diseases (ICD)-9 diagnostic codes, Abbreviated Injury Severity Scale (AIS-2005) for each injury, and an overall Injury Severity Score. These detailed injury profiles were integrated into intelligence investigations into tactical events resulting from insurgency activity against U.S. assets. The ability to define injury and severity and then link these to the investigations of the tactical events allows the intelligence and materiel communities to track the evolution of the insurgency threat and test and evaluate the effectiveness of countermeasures.



Chapter 4

KEY PROGRAM ACCOMPLISHMENTS

The Blast Injury Research PCO was established to coordinate the large number of relevant efforts that can 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.

The Blast Injury Research PCO developed a web-based data collection tool to streamline its DoD-wide blast injury research data collection efforts and provide a single repository for researchers from across the DoD to detail their research efforts along with their significant accomplishments.

In January 2010, the PCO solicited program information and significant accomplishment data from the Component- and DoD-level organizations conducting blast injury research.

This chapter summarizes the key blast injury research program accomplishments submitted in response to this data call, arranged by research topic, and highlights the collaborations among diverse organizations that are committed to providing Soldiers, Sailors, Airmen, and Marines with the very best blast injury prevention, mitigation, and treatment solutions.

Injury Prevention

Computational Biology—Modeling of Primary Blast Effects on the Central Nervous System

Recent military conflicts in Iraq and Afghanistan have highlighted the wartime effect of TBI. The reason for the prominence of TBI in these particular conflicts as opposed to others is unclear but may result from the increased survivability of blast due to improvements in body armor. Scientists at the Defense and Veterans Brain Injury Center (DVBIC) hypothesized that, using biofidelic models, a blast wave would interact with central nervous system (CNS) tissue and cause a possible concussive effect. Researchers used a computational framework suitable for simulating coupled fluid-solid dynamic interactions to compare the effects of threshold and 50% lethal [LD_{50}] blast lung injury with concussive effects to be similar between impact-induced mild TBI and the blast field associated with a LD_{50} lung blast injury sustained without PPE. This suggests that blast concussive effects may be more readily ascertained in personnel due to enhanced survivabilty in the current conflicts. The findings were published in *Neuroimage*, 2009 Aug; 47 Suppl 2:T10-20. Epub 2009 Feb 24.

Dynamic Entry Training Not a Risk for TBI

The Office of Naval Research (ONR) completed its study at the U.S. Marine Corps Dynamic Entry School, Quantico, Virginia. The breacher injury study examined the effects of repeated blast exposures to Marines training to use explosives to gain rapid entry into structures. The data indicated that students undergoing breacher training were not at risk of suffering TBI during training.

Focus Headform Used to Evaluate Novel Face and Eye Protective Countermeasures

The ARL developed a methodology for experimental impact tests utilizing the FOCUS (Facial and Ocular Countermeasures Safety) headform to determine injury criteria for hyphema, lens dislocation, and retinal damage. The ARL

conducted a meta-analysis using existing injury impact tests on human cadavers and animal surrogates published in open literature. The test configuration was designed and built to accommodate a variety of projectiles to evaluate a range of normalized energy.

Health Risk Communication Added to the VA/DoD Clinical Practice Guideline for Management of Concussion and Mild TBI

The U.S. Army Public Health Command (Provisional) (USAPHC) developed a Health Risk Communication appendix for the VA/DoD Clinical Practice Guideline, Management of Concussion/mTBI. Although penetrating TBI is typically identified and cared for immediately, mTBI may be missed, particularly in the presence of other more obvious injuries. Due to numerous deployments and the nature of enemy tactics, troops are at risk for sustaining more than one mild brain injury or concussion in a short time frame. The guideline can be found at http://www.healthquality.va.gov/management_of_concussion_mtbi.asp.

Impedance Threshold Device Reduces Intracranial Pressure with Each Inspiration

Researchers at the Department of Combat Medic Training, Fort Sam Houston, Texas developed an impedance threshold device with 7 cm H_2O resistance (ITD-7) that increases blood pressure in hypotensive animals and patients. Breathing through the device also reduces intracranial pressure (ICP) thereby providing greater blood flow to the brain. The device may be able to buy time in hypotensive Warfighters when other therapies are not readily available. The work is published in an article, "The impedance threshold device (ITD-7)—a new device for combat casualty care to augment circulation and blood pressure in hypotensive spontaneously breathing warfighters," *J Spec Oper Med.* 2009 Spring;9(2):49-53

Intracellular Fluid Cavitation, a Possible Mechanism of Injury Following Exposure to Blast

The ONR completed Finite Element Model studies demonstrating cavitation in intracellular fluid following exposure to blast as a possible mechanism of TBI. The research has transitioned to a Phase II Small Business Innovation Research award at the DARPA.

BURNSIM Model Predicting Battlefield Injuries Integrated, Verified, and Validated into ORCA

The ARL updated and integrated the thermal burn insult module (BURNSIM) into the Operational Requirement-based Casualty Assessment (ORCA) model system and verified and validated the model. BURNSIM is a thermal burn injury model originally developed at the U.S. Army Aeromedical Research Laboratory (USAARL) and further extended at the Air Force Research Laboratory. AIS 2005, Update 2008 was integrated into ORCA for improved injury characterization and extended to include BOP and thermal burn in addition to penetration insults and verified and validated. The verification and validation report was submitted to the U.S. Army Test and Evaluation Command for accreditation.

Wound Ballistics Database Grows and Supports Injury Model Improvement

The SLAD continued to populate an Army wound ballistics database for archiving historic wound ballistics notebooks and associated data. Indices for 412 of 610 (68%) notebooks have been developed. Accessibility to this information has helped researchers and developers improve injury models for various insults, most recently for blunt trauma and thermal burn. In addition, data extracted from the notebooks was used in the verification and validation of a thermal burn model, BURNSIM, and integrated into the ORCA model system in support of the M915A5 Line Haul, Truck Tractor Crew Vulnerability Evaluation. A limited distribution report, "Verification and Validation Report for the Operational Requirement-based Casualty Assessment (ORCA) Version 2.2 Model in Support of the M915A5 Line Haul, Truck Tractor Crew Vulnerability Evaluation" was provided to the U.S. Army Test and Evaluation Command through the U.S. Army Evaluation Center.

Acute Treatment

Advances in Extended Life Red Blood Cells (RBC) Research

The U.S. Army Medical Materiel Development Activity (USAMMDA) in partnership with Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire and Hoxworth Blood Center, University of Cincinnati, Ohio completed in vitro testing of extended life RBC. In another partnership with regulatory sponsor (Hemerus Medical, LLC, Saint Paul, Minnesota), successfully applied for investigational new drug (IND) status for RBC, extended life as a necessary precondition before proceeding to pivotal clinical study.

Advances in Cryopreserved Platelets Research

The Walter Reed Army Institute of Research (WRAIR) in collaboration with the Dartmouth-Hitchcock Medical Center, Lebanon, New Hampshire successfully prepared an IND status application package for cryopreserved platelets for information to the U.S. Food and Drug Administration (FDA). Furthermore, the team defined and demonstrated the necessary processes and procedures for the manufacturing and product stability of cryopreserved platelets, a necessary precursor to planned clinical testing.

Freeze-Dried Platelets Research Moves to Clinical Trials

USAMMDA partnered with HemCon Medical Technologies, LLC, Portland, Oregon to coordinate and conduct all activities and meetings with the FDA supporting submission of the IND application for freeze-dried platelets (FDP); establish a good manufacturing practice-compliant pilot production facility for production of product for Phase 1 and Phase 2 clinical studies; and produce and test multiple prototypes of intended battlefield-hardened packaging for FDP and arrived at a near-final prototype. The pilot production facility was developed within HemCon Medical Technologies main manufacturing facility in Tigard, Oregon.

Biocompatibility Testing of RBC Collection and Storage System Components Completed

USAMMDA in partnership with regulatory sponsor (Hemerus Medical, LLC, Saint Paul, Minnesota) completed biocompatibility testing of RBC collection and storage system components for extended life RBC. This testing is a necessary precondition for ultimate FDA approval and licensure.

Blast-Induced Neurotrauma Could Explain Long-Term Cognitive Effects

Studies of biomechanics and neurodeficits supported by the ONR show that a 16 psi blast is more injurious to a rat than lower and higher pressure blasts possibly due to the shape and dynamics of the rat skull. Histological analysis confirms this effect in the hippocampal dentate gyrus, where new neurons form from endogenous stem cells. This could potentially explain the long-term cognitive effects observed specifically with blast-induced TBI.

Case Report of a Soldier with Primary Blast Brain Injury

The DVBIC described a case report involving primary blast injury of the CNS in a Service member exposed to a large ordnance explosion. The report describes neuroimaging abnormalities together with normalization of the fractional anisotropy on diffusion tensor imaging (DTI) after follow-up imaging studies. This case report was published in *Neuroimage*, 2009 Aug; 47 Suppl 2:T152-3. Epub 2009 Feb 10 and was presented at The American Journal of Nursing 2009 National Conference.

Clinical Assessments of Novel Medical Interventions in a Military Critical Care Environment

The USAMRMC Combat Casualty Care Research Program (CCCRP) coordinated clinical assessments of novel medical interventions in a military critical care environment. The clinical assessments demonstrated: the utility of continuous venovenous hemofiltration in decreasing mortality in the severely burned; identified late abdominal catastrophes (bowel ischemia) in the severely injured as separate from abdominal compartment syndrome; and demonstrated the efficacy of Silverlon dressing of donor sites to improve healing and pain management.

Fast-Resorbing Pellets Release Antibiotics Rapidly and at Therapeutic Levels

The CCCRP in collaboration with researchers at The Joint Program in Biomedical Engineering at The University of Memphis and The University of Tennessee, Herff College of Engineering evaluated in vitro small pellets engineered to resorb rapidly and deliver high local doses of antibiotic (amikacin, gentamicin, or vancomycin) to the wound site while minimizing systemic effects. The pellets dissolved in 12-16 hours and released therapeutic antibiotic levels that were above the minimal inhibitory concentration for growth of *P. aeruginosa* and *S. aureus* for the life of the pellet. For additional information, see "Preliminary in vitro evaluation of an adjunctive therapy for extremity wound infection reduction: rapidly resorbing local antibiotic delivery," *Journal of Orthopedic Research*, 27(7), 2009.

Diffusion Tensor Imaging Study Shows Blast Injury May Cause Brain Inflammation

Researchers from the DCoE for PH/TBI used DTI to demonstrate that veterans who sustain mTBI caused by blasts have a different pattern of injury than their counterparts who suffer mTBI as a result of a direct hit to the head that does not involve an explosion. Veterans with blast-related mTBI had a diffuse pattern of injury involving more of the brain's white matter. The apparent diffusion coefficient was also lower in blast-related injury, possibly indicating swelling or inflammation similar to what occurs in the brain with infection or stroke. DTI in blast patients was different from the pattern seen for the traditional impact forms of TBI, which again was different from healthy controls who had not sustained a head injury. Persistent CNS damages appear to occur with both blast-associated and impact mTBI but with greater severity and spatial extent in blast-associated mTBI patients. These findings were presented at the 2009 annual meeting for the American Academy of Neurology.

Propranolol Fails to Decrease PTSD Development in Burned Soldiers

Scientists from the U.S. Army Institute of Surgical Research (USAISR) conducted a retrospective study to examine the relationship between PTSD prevalence and propranolol administration. The resulting data indicated that propranolol administration did not decrease the development of PTSD in burned Soldiers. Results were published in a paper, "The effect of propranolol on PTSD in burned Service members," *Journal of Burn Care Research*, 2009 Jan-Feb;30(1):92-7.

Topiramate Attenuates Nonconvulsive Seizure (NCS) Episode Duration in Rats

Scientists from the WRAIR conducted an antiseizure therapy study in the post-blast brain injury (PBBI) model. The study evaluated the effects of topiramate against PBBI-induced NCS. Study results demonstrated that a maximal water-soluble dose regimen (30 mg/kg initial bolus dose, followed by daily 15 mg/kg maintenance dose) significantly attenuated NCS episode duration. However, its effects on NCS incidence and frequency are minimal. Results were presented in a research poster entitled "The Effect of Topiramate on Electroencephalography in a Model of Penetrating Ballistic-Type Brain Injury in Rats" at a National Neurotrauma Society meeting in Santa Barbara, California.

Treatment with N-Acetylcysteine Amide Results in Less Pulmonary Damage

The ONR completed single blast studies conducted at 40, 70, and 120 kPa. Injury was observed only at the highest pressure in brain and lungs. Treatment with the antioxidant N-acetylcysteine amide resulted in less pulmonary damage with the antioxidant at 120 kPa. Study results to date showed that side-on impact is worse than face-on impact. These results have been reported in "Attenuation of pulmonary inflammation after exposure to BOP by N-acetylcysteine amide," http://www.ncbi.nlm.nih.gov/pubmed/19174737.

Reset

Advanced Hardened C-Leg

The Military Amputee Research Program (MARP) funded Otto Bock Healthcare Products, Inc. to develop the Advanced Hardened C-Leg. This is a microprocessor-controlled prosthetic knee that meets user requirements from initial fitting through returning the user to the highest levels of function to include walking, running, and climbing. This prosthetic device offers the potential of replacing up to six separate lower limb prostheses with one device, which will perform at levels equal to or higher than those it replaces, and is currently being assessed.

Extracellular Matrix Powder Helps Regrow Damaged Tissue

The USAISR, in collaboration with the Armed Forces Institute of Regenerative Medicine (AFIRM) used an extracellular matrix powder, developed by the University of Pittsburgh, to lengthen the index fingers of two burned Soldiers. In one, the finger grew about 5 mm longer. The other patient stopped applying the powder and saw no length gain. The USAISR also used a sheet form of the extracellular matrix in an attempt to grow back the quadriceps (thigh) muscle in two wounded Soldiers. Results showed approximately an 11% increase in muscle mass. The AFIRM Annual Report 2009 provides additional detail at http://www.afirm.mil/assets/documents/annual_report.pdf).

First Face Transplant in the United States

AFIRM scientists from the Cleveland Clinic demonstrated the clinical feasibility of reconstructing tissue loss in the face following severe trauma by completing the first near-total face transplant in a civilian patient in the United States (Figure 4-1). The patient had lost her maxilla, nose, and floor of the orbits and tried for 2 years to get a functional surgical repair with no real success. She could not smell, could not eat or drink, could not talk, and needed a tracheostomy to breathe. She is now nearly 1 year post surgery and doing well. The AFIRM Annual Report 2009 provides additional detail at http://www.afirm.mil/assets/documents/annual_report.pdf.

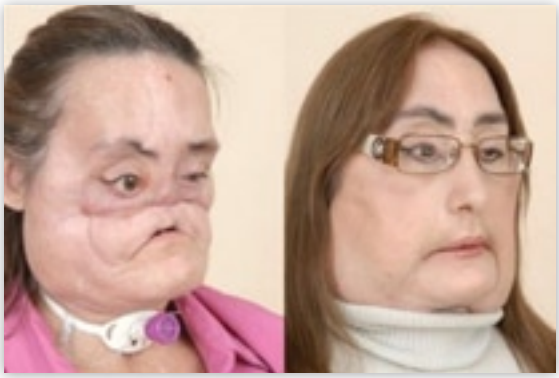


Figure 4-1. First U.S. Face Transplant Performed by AFIRM Researchers at the Cleveland Clinic, December 2008

Marine Receives First Hand Transplant in the United States

AFIRM scientists from the University of Pittsburgh performed hand transplantation on a former Marine who lost his hand in a training accident while on active duty (Figure 4-2). They also performed the U.S.'s first bilateral hand transplant as well. Both patients also received bone marrow-induced immune tolerance. As a result, they are now on a minimal immunosuppression regimen without any adverse side effects. The AFIRM Annual Report 2009 provides additional detail at http://www.afirm.mil/assets/documents/annual_report.pdf.

Figure 4-2. First Two U.S. Hand Transplants Using Bone Marrow-Induced Immune Tolerance by AFIRM Researchers at the University of Pittsburgh, March 2009

New Model for Compartment Syndrome

AFIRM scientists from the Stem Cell Research Center in Pittsburgh created an abdominal wall defect model in the rat for the assessment of biodegradable scaffolds being developed to treat compartment syndrome. This syndrome results from inflammation after surgery that leads to increased pressure, impaired blood flow, nerve damage, and muscle death. The AFIRM Annual Report 2009 provides additional detail at http://www.afirm.mil/assets/documents/annual_report.pdf.

Advanced Engineered Skin Substitute Models

AFIRM scientists from the University of Cincinnati established an advanced engineered skin substitute models with skin pigmentation and a supply of blood vessels (Figure 4-3). They are developing engineered skin substitutes, consisting of various types of skin cells attached to a collagen-based matrix and are conducting clinical tests as an adjunctive treatment for burn repair. Additional detail provided in the AFIRM Annual Report 2009 at http://www.afirm.mil/assets/documents/annual_report.pdf.

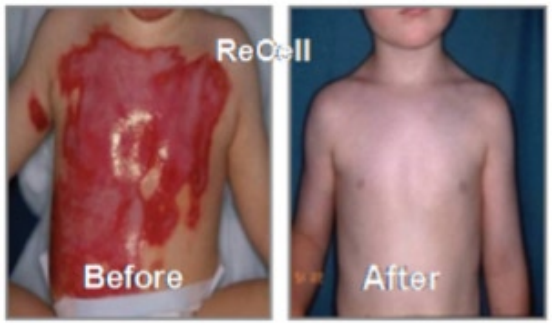


Figure 4-3. Engineered Skin Substitutes

Wound Healing Without Scarring

AFIRM researchers from Stanford University capitalized on the ability of wounded fetal tissue to regenerate with minimal scarring by developing a regenerative bandage containing a fetal-like matrix and stem cells derived from human amniotic fluid. This bandage is being refined so that it will maintain an acute wound in a pro-regenerative state and prevent the onset of scarring, fibrosis, and infection. The AFIRM Annual Report 2009 provides additional detail at http://www.afirm.mil/assets/documents/annual_report.pdf.

Figure 4-4. Prototype of the Spray Head and the Processor-Controlled Pneumatic

Active Wound Dressing for the Support of Progenitor Cells

AFIRM scientists from the University of Pittsburgh established an in vitro cell spray model and an in vitro wound capillary membrane model of an active wound dressing for the support of progenitor cells, which work with fetal skin fibroblasts and keratinocytes (Figure 4-4). They also established laboratory methods for the isolation and cell culture of fetal skin stem cells. Additional detail provided in the AFIRM Annual Report 2009 at http://www.afirm.mil/assets/documents/annual_report.pdf.

Ongoing Research Efforts from the FY07 PTSD/TBI Competitive Research Program Awards

Comprehensive 3-D Model of Shock Wave-Brain Interactions in Blast-Induced Traumatic Brain

At the University of Washington, investigators propose the development of a simulation tool that couples a blast wave to the skull, resulting in kinetic motion. The primary objective of this work is the software development of a 3-D, 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. Secondary objectives include the development of a graphical user interface to the numerical kernel for ease of use of the software and of a self-contained graphical application for the visualization of the computed results. The Principal Investigator (PI) has developed sequential and parallel kernel versions of a fully 3-D model for both acoustic and elastic wave propagation on fixed computational grids based on the pseudospectral time domain method. In addition, 2-D sequential kernels for acoustic wave propagation based on the wavelet time domain method were developed, which includes adaptive grid refinement. The analytical representation of the effective medium theory for the different media present in the human head was also constructed, and the necessary effective wave numbers were determined. The PI has also validated both the sequential and parallel implementations of the acoustic and elastic wave propagation kernels based on pseudospectral methods against other published work. In addition, the nonlinear acoustic propagation model against experimental data available in the PI's laboratory through other projects has been validated. Segmentation, labeling, and reconstruction of the head region of the Visual Human Project man have also been completed.

Computational Modeling of Causal Mechanisms of Blast Wave-Induced Traumatic Brain Injury: A Potential Tool for Injury Prevention

At WSU, investigators are characterizing the effects of blast waves produced by various explosions in respect of resulting response in the head/brain using a sophisticated, anatomically inspired, and biomechanical FE model of human head. The specific aims of this research are to: (1) Simulate blast waves generated by a variety of explosions in a variety of surroundings and to quantify overpressure profiles interacting with the head at various orientations using a biomechanically based FE model of the human body; (2) quantify the pattern of the shock wave as it travels through various structures of the head/brain and the resulting mechanical responses (peak pressure, duration, rate of pressure rise, shear stress, and shear stress rate) in various

parts of brain using an anatomically detailed biomechanical head model; and (3) establish the relationships between localized brain response (internal) parameters with blast wave (external) on the head from various conditions to delineate dose-effect mechanisms contributing to blast TBI.

The similarities and differences of brain response patterns between the blunt trauma and blast trauma will be compared to evaluate the predictive ability of the biomechanical head model. To date, the PI has determined that: (1) a person in a prone head-on position subjected to a ground explosion would sustain greater damage to the brain than a person standing in a free blast condition; (2) the maximum peak pressure transmitted to the scalp, skull, and brain was higher than the blast pressure received by the head; (3) increasing levels of BOP produced higher ICP and principal strain; (4) the effects of being adjacent to a reflecting wall are noticeable only on the region of the brain closest to the wall; (5) the overall peak responses are dominated by the effect of the blast wave front on the regions of brain facing the blast wave; (6) the damage effect to the brain was strongly dependent on impulse (momentum transfer) in short duration blasts; and (7) a blast wave reflected by the ground greatly contributed to increased pressure responses and head acceleration.

Diagnosing Blast-Induced TBI Using Advanced MRI Techniques

Investigators at Washington University are testing two advanced MRI methods, DTI and resting-state fMRI, in active-duty military blast-related TBI patients within 4 days of injury and correlating the findings with TBI-related clinical outcomes 6–12 months later. Traumatic axonal injury is a principal cause of impaired brain function following blast-related TBI. The study's specific aims are: (1) to assess the extent of acute blast TBI-related abnormalities using DTI and resting-state fMRI that are not apparent on conventional MRI scans; (2) to determine specific patterns of imaging abnormalities that predict specific TBI-related clinical outcomes; and (3) to develop acute imaging predictors of overall 6–12 month clinical outcomes. To date, 63 subjects have been enrolled including 43 blast-related TBI patients. Preliminary analyses of initial scans have revealed abnormalities on DTI indicative of traumatic axonal injury in 20 out of 43 injured subjects that were not detectable on conventional MRI or CT.

Epidemiological Study of Mild Traumatic Brain Injury Sequelae Caused by Blast Exposure During Operations Iraqi Freedom and Enduring Freedom

Investigators at the McGuire Research Institute, Inc. are studying the sequelae induced by blast exposure in those with mTBI. The overall goals of this project are to utilize a cross-sectional design to determine the prevalence of post-concussive syndrome (PCS) after blast-related mTBI, characterize symptoms, and allow for predictive modeling (Phase I); employ a case-control design to evaluate objective abnormalities among subjects with PCS after mTBI (Phase II); and conduct a longitudinal design to analyze outcomes overtime (Phase III). *Status Update:* To date, the PI has received institutional review board approvals, hired and trained staff, refined the study procedures, recruitment, data management and analyses, and screened over 300 potential subjects, 34 of which were recruited for Phase I. For a subset of the 34 subjects, cognitive and neuropsychological data as well as computerized posturography have been collected in Phase II.

Glyburide—Novel Prophylaxis and Effective Treatment for Traumatic Brain Injury

At the University of Maryland, Baltimore, investigators are conducting a study to: (1) determine the efficacy of glyburide in a battery of animal models relevant to TBI, including severe contusion, moderate frontal impact closed-head injury, blast injury and in a polytrauma model with moderate TBI complicated by hemorrhagic shock; (2) validate the utility of early diagnosis of TBI using brain acoustic monitoring by correlating with MRI in a large animal model following blast brain injury; (3) collect fresh biopsy specimens from humans post TBI that undergo brain surgery at the University of Maryland Shock Trauma Center, to evaluate the timing, extent, and location of SUR1 upregulation in human TBI; and (4) confirm the "neurobehavioral safety" of prophylactic use of glyburide in humans taking it for 1 week, using neuropsychological and behavioral tests, and assuring safety with serum glucose and glyburide levels. During the first year of the project, the investigator completed devel-

opment, construction, and implementation of a cranial-only blast injury apparatus (COBIA). Using COBIA, the investigator began characterizing the pathophysiological consequences of blast TBI, with early results suggesting the novel observation that blast TBI can produce fatal neurogenic pulmonary edema independent of blast injury to the thorax. Blast TBI also caused significant, sustained impairment in the Rotarod test of behavioral and motor performance. The investigator found significant effects of blast-TBI on capillary integrity (indicated by IgG uptake), apoptotic death signaling (indicated by activated caspase-3), and neuronal injury (indicated by increased β-amyloid precursor protein). The investigators have also began characterizing the effect of blast TBI on the SUR1-regulated NCCa-ATP channel, with early results suggesting the novel finding that SUR1 is abundantly upregulated in neurons and oligodendrocytes.

Kevlar Vest Protection Against Blast Overpressure Brain Injury: Systemic Contributions to Injury Etiology

Emerging data from researchers at the WRAIR reveal that a protective vest encasing the thorax ameliorates blast-induced brain injury, pointing to a significant contribution of the effects of blast on the thorax to brain injury pathophysiology. The hypothesis is that much of the blast-induced fiber degeneration in brain results from pressure surges transmitted through the vasculature (venous as well as arterial) that elicit a series of intracranial disruptions and that Kevlar vests are neuroprotective by uncoupling this pressure transmission following exposure to blast. Using a compression-driven shock tube, the team proposes to measure, compare, and correlate external, systemic (e.g., vascular arterial and venous), and central (e.g., ICP) BOP-induced pressure changes, and assess the impact of Kevlar vests on these changes. The study aims to: (1) determine if measured pressure changes are blast severity-dependent and correspond with neuropathological and neurobehavioral outcome measures and (2) assess the impact of Kevlar vests on measured BOP-induced changes and outcome measures. To date, the investigators have found preliminary evidence of improved neuropathology, behavior, and survival with the use of protective Kevlar vests in rats compared to unprotected rats following air blast injury.

Loss of Ceruloplasmin Ferroxidase Activity Contributes to Neuronal Injury After Blast Exposure

Blast exposure is frequently associated with bleeding in the brain and the constriction of blood vessels. Following blast exposure, blood accumulates outside vessels and releases iron around the site of injury. If this iron is not removed from the brain, it can cause oxidative injury to the neurons. Scientists from WRAIR have demonstrated that the build-up of iron may also lead to the accumulation of asymmetric dimethyl arginine (ADMA), a compound that causes the constriction of blood vessels. This animal study will examine the hypothesis that the injury to the neurons of the brain and the accumulation of ADMA result in part from a disruption of the normal mechanism to remove iron from the brain. Specifically, the PI will correlate changes in cellular iron in the brain with changes in the ferroxidase activity of ceruloplasmin and to determine if the injection of a functional ferroxidase can decrease cellular iron accumulation after blast injury. Additionally, the PI will determine whether changes in intracellular iron are associated with levels of ADMA in the cerebral spinal fluid (CSF). *Status Update:* Research was initially delayed because the PI took a medical leave of absence. Since returning, the PI developed a ferroxidate activity assay and has begun collecting samples. Preliminary data indicate that hemorrhaging decreases plasma ferroxidase activity.

Measuring Intracranial Pressure and Correlation with Severity of Blast Traumatic Brain Injury

At the Detroit Research and Education Foundation, the investigators intend to understand how pressure is transmitted through the brain and ascertain the relationship between levels of pressure transmission with severity of brain injury. The hypothesis is that tissue structures and varying densities in the head determine the pathway of pressure wave transmission. The specific aims of this study are to: (1) map the transient ICP as a function of blast magnitude, (2) map the transient ICP as a function of head orientation, and (3) ascertain injury severity as a function of ICP. The PI used a shock tube model in animals to conduct a series of studies of blast-stress transmission to the brain, demonstrating that proper sealing techniques are required to accurately measure ICP.

ICP was demonstrated to be increased as compared to ambient overpressure. Optimizing the sealing procedures and instrumentation of animals found that ICP during blast is significantly higher in the brain as compared to ambient overpressure, determined that pressure sensor location has a major role in accurate pressure measurements, and developed protocols for multiple pressure recordings during blast testing.

Military Blast-Related Traumatic Brain Injury: A Study of Isolated Shock Waves on Central Nervous System Injury

At the Henry M. Jackson Foundation, investigators are studying the effects of shock waves on CNS injury. This project seeks to isolate the pressure or mechanical strain component of the blast by developing extracorporeal shock wave lithotripsy devices to generate and isolate the shock wave overpressure component to study the interaction of this component of the blast wave with CNS model systems, ex vivo CNS tissues, and a nonlethal primate model. To date, the investigation has begun to describe the effect of mechanical strain on agarose gels of varying concentrations and has found evidence for shear thickening of the medium as the strain rate increases. Additionally, further exploration of gels and simple fixed tissue slices of mouse brain across the strain rate continuum using a specially manufactured split Hopkinson of Kolsky bar is being pursued.

Pathological Fingerprints, Systems Biology, and Biomarkers of Blast Brain Injury

Investigators at Banyan Biomarkers, Inc. are exploring biochemical pathways, creating an interactive map, and developing and validating a panel of sensitive and specific biomarkers of blast-induced brain injury for diagnostics and future directed pharmacological mitigation. To date, investigators have defined the blast impact index as a combined function for blast wave magnitude at the body surface (peak overpressure), duration, and impulse power. In addition, results obtained thus far show that severe damage is accompanied by strong positive staining in several deep brain areas, suggesting diffused and focal neurodegeneration. Increases in glial fibrillary acidic protein were also discovered in the hippocampus after 7 days and lasted until day 30 post blast, with accumulations of CNPase in the hippocampus seen 24 hours after blast and remaining elevated until day 30.

The Effects of Explosive Blast as Compared to Post-Traumatic Stress Disorder on Brain Function and Structure

Investigators at the VA Medical Center in Minneapolis, Minnesota, are using quantitative indices of brain electrical activity and DTI to characterize the effects of blast injury on brain function and structure. The hypothesis is that OIF Soldiers injured by explosive blast will be distinguishable from those with PTSD on measures of brain function and structure. The study aims to determine: (1) the nature of functional neural anomalies related to sustained attention and memory deficits evident after injury from blast; (2) white matter anomalies that are unique to blast injury as compared to PTSD; and (3) aspects of blast-related functional and structural brain abnormalities that are associated with adaptive functioning in postdeployment. To date, the investigator has developed a consensus procedure for rating severity of brain injury due to blast and non-blast events based on subjects self-reporting and new staff members have been hired to initiate and conduct the study. A total of 37 potential participants completed the phone screen; of these, 11 were ineligible and 9 declined the invitation to participate in the study. Sixteen study participants have been enrolled and are in the process of completing the study; 11 of these participants are control subjects (no blast injury, no PTSD), 2 are in the blast only group, 1 is in the PTSD only group, and 2 are in the blast injury plus PTSD group.

Treatment of TBI with Hormonal and Pharmacological Support, Preclinical Validation Using Diffuse and Mechanical TBI

An extension of the successfully completed DARPA-funded phase I and II Surviving Blood Loss programs is assessing whether the intravenous administration of high dose, soluble estrogen will decrease the damage of TBI, from blast wave-induced injury. Researchers are also investigating whether combination(s) of estrogen with glucosamine and/or erythropoietin and progesterone will augment and enhance the neuroprotective and reparative properties of estrogen for injured brain and nervous system tissues. Results obtained

thus far indicate that administration of estrogen 1 hour after injury in rats significantly reduces edema compared to untreated controls.

Understanding the Brain Mechanism Underlying Depression in Combat-Related Traumatic Brain Injury

Investigators at the University of San Diego are examining the degree to which blast-related TBI disrupts the connections between brain regions involved in emotion processing (i.e., amygdala) and structures involved in the cognitive control (CC) of emotion (i.e., dorsal anterior cingulate cortex), and the extent to which such disruptions are related to increased depressive symptom severity and impaired psychosocial functioning. This study aims to examine the neural substrates of CC in two groups of individuals who have sustained blast-related TBI (i.e., TBI individuals with and without current major depressive disorder [MDD]), and the degree to which deficient CC is associated with clinical and psychosocial impairment. To date, the study has found that the TBI with MDD (TBI+MDD) group endorsed loss of consciousness significantly more often and displayed significantly greater activation in bilateral amygdala during fearful face matching and had significantly more severe symptoms of depression. It has also been determined that the group differences in task-related brain activity were not driven by behavioral differences between the groups and that the severity of PTSD symptoms did not account for the observed differences in functional brain activation.

Chapter 5

DOD INVESTMENT STRATEGY

Actual blast injury research investments in FY09 increased by $89M from FY09 forecasts in the Blast EA's first annual report in January 2007—**A 95% INCREASE!**

Table 5-1. DoD Blast Injury Research Investments ($K), FY09–17
(as reported to the DoD Blast Injury Research Program Coordinating Office - April 2010)

Service Agency	Program Element	FY09	FY10	FY11	FY12-17
Army	0601102A: *Medical Technology*	2,101	9,570	10,864	74,653
	0601103A: *University Research Initiatives*	1,752	0	0	0
	0602787A: *Medical Technology*	52,467	53,440	53,208	288,914
	0603002A: *Medical Advanced Technology*	77,264	48,158	49,862	292,356
	0603807A: *Medical Systems - Advanced Development*	3,152	4,638	793	9,000
	0604807A: *Medical Materiel/Medical Biological Defense Equipment*	6,251	8,595	9,035	60,175
	0605604A: *Survivability/Lethality Analysis*	150	150	150	600
	OMA/OCO (JTAPIC)[1]	18,765	17,800	0	0
Army Total		**161,902**	**142,351**	**123,912**	**725,698**
DHP[2]	0601117HP: *Basic Operational Medical Resarch Sciences*	0	41,000	0	0
	0602115HP: *Applied Biomedical Technology*	0	84,384	22,370	102,775
	0603115HP: *Medical Technology Development*	13,704	7,110	26,275	327,916
	0604110HP: *Medical Products Support and Advanced Concept*	0	110,127	77,956	243,457
	0605145HP: *Medical Products and Support Systems Development*	0	824	0	261,483
DHP Total		**13,704**	**243,445**	**126,601**	**935,631**
OSD	0601111D8Z: *Government/Industry Co-sponsorship of University*	1,703	0	0	0
	0603122D8Z: *Combating Terrorism Technology Support*	714	1,191	0	0
OSD Totals		**2,417**	**1,191**	**0**	**0**
Navy	0602236N: *Warfighter Sustainment Applied Research*	510	0	0	0
	0603729N: *Warfighter Protection Advanced Technology Development*	2,816	2,400	2,750	21,935
Navy Totals		**3,326**	**2,400**	**2,750**	**21,935**
Grand Total		***181,349***	***389,387***	***253,263***	***1,683,264***

[1] These funds were received by the JTAPIC Partnership via an Army Asymmetric Warfare Office (AAWO) sponsored Overseas Contingency Operations (OCO) war supplemental request. Because baseline funding for the JTAPIC program has yet to be programmed/approved, JTAPIC funding requirements beyond FY10 are not shown.

[2] Funding information for DHP-funded projects was provided beyond FY15.

The figures in Table 5-1 represent the current DoD investment in blast injury research as reported to the Blast Injury Research PCO during its most recent DoD-wide data call, which concluded in April 2010. Great care was taken to include all organizations involved in blast injury research throughout the DoD in this data call; however, as the list of organizations involved in blast injury research grows, this table should not be considered to be an exhaustive, all-encompassing list. Additionally, as the various DoD accounting systems do not specifically identify blast-related research investments, the information provided relies on the accuracy of the data reported to the PCO.

Key Components of the Blast Injury Research Program

Chapter 6

KEY COMPONENTS OF THE BLAST INJURY RESEARCH PROGRAM

The Program facilitates collaborative research among laboratories of the DoD, other federal agencies, academia, and industry to solve complex problems by leveraging the body of knowledge that resides both within and outside the DoD.

Deployment Related Medical Research Program (DRMRP)

Congress authorized $273.8M in the FY08 War Supplemental to fund battle casualty and psychological health research. These funds were targeted to accelerate ongoing programs and for peer-reviewed research into emergent approaches and technologies. The research areas included (see Table 6-1 for details): final development of medical devices for use in theater (including portable suction machines and ECGs for theater hospitals); blood safety and blood products; burns (including tissue viability and fluid resuscitation); orthopedic and trauma treatment and rehabilitation (including face, visual/ocular and nerve damage, dental, and auditory systems); suicide prevention and counseling (including reducing nurse stress and fatigue at military treatment facilities); TBI/PH (including PTSD); injury prevention; wound infection and healing; treatment for severe cutaneous leishmaniasis; and wound infection vaccines.

Table 6-1. Detailed Research Gaps in Each Topic Area

Topic Area	Research Gap
Blood Safety	• Pathogen inactivation of platelets
	• Pathogen inactivation of whole blood
Blood Products	Freeze-dried plasma products with the following characteristics:
	• Human plasma derived
	• Pathogen inactivated or pathogen free
	• Temperature stable
	• Lipid reduced
Injury Prevention	Biomedically valid computational models of blast-related injuries that can be used to design, build, and test:
	• Personal protection systems, such as combat helmets and body armor
	• Combat vehicle protection systems, such as blast-attenuating seats
Final Development of Medical Devices for Use in Theater	• FDA-approved, rapid detection, multiplex/multiagent, handheld systems designed to screen whole blood pre-transfusions and accurately detect bloodborne pathogens with a high degree of sensitivity and specificity for use far-forward in a wartime environment
	• Highly portable, autonomous or semiautonomous ventilation and resuscitation systems
	• Web-based, telemedicine modality clinical technologies

Table 6-1. Detailed Research Gaps in Each Topic Area (cont.)

Topic Area	Research Gap
Traumatic Brain Injury (TBI)	• Epidemiology with emphasis on battle-induced mild TBI (mTBI) and PTSD analyzing the occurrence and development of symptoms including, but not limited to, repetitive injury, sleep disturbances, and cognitive and emotive symptoms (e.g., risk-taking behavior and substance abuse). Effort should be directed to determining the actual incidence of mTBI on the battlefield, its effects on performance of mission, and its long-term sequelae.
	• Phase 2 or 3 clinical trial(s) for pharmacological treatment of TBI including single or combination therapies
	• Impact of patient transport (e.g., ground and rotary/fixed-wing air) on moderate and severe TBI, and techniques and/or therapies designed to reduce negative impact
	• A simple, quantitative, noninvasive method to diagnose mTBI that can be used for deployed troops
	• Sensors, including accelerometers and dosimeters, to measure blast and predict the occurrence of TBI
	• Efficient clinical diagnostic criteria methodologies for detecting mTBI while distinguishing it from psychological comorbidities (i.e., depression and PTSD)
	• Pain management to improve short-term outcomes and reduce the risk of long-term opioid dependence and/or abuse
	• Innovative therapies for TBI, including hyperbaric oxygen therapy and complementary and alternative medicine
	• Impact of rehabilitation strategies on neural plasticity and neurogenesis following TBI, using imaging, neurobiological, cognitive, and pharmacotherapeutic approaches so as to improve quality of life or ability to function in home and community life
	• Conclusive data on the existence and tissue-level mechanisms of nonimpact, blast-induced mTBI to support the development of effective preventive measures, diagnostic tools, and treatments
Psychological Health, Including Post-Traumatic Stress Disorder (PTSD)	• Clinical trials focused on universal and selective interventions for prevention of combat deployment-related mental health and post-deployment reintegration concern
	• Clinical trials for the treatment of combat-related psychological health problems, including PTSD and depression, and comorbid psychosocial disturbances among Operation Iraqi Freedom and Operation Enduring Freedom (OIF/OEF) veterans
	• Evidence-based screening, brief interventions, and referral for treatment (SBIRT) among Service members that can be employed across levels of care, care providers, and deployment cycle with particular emphasis placed on post-deployment
	• Clinical rehabilitative-treatment trials to treat and manage combat-related persistent or chronic postconcussive symptomology, or co-occurring physical and mental health symptoms
	• Evidence-based interventions to provide “care for the caregiver” focusing on reducing physical and psychological stress among primary care providers, nurses, mental health providers, and chaplains involved in the care of OIF/OEF Service members
	• The impact of military life on quality of life/health indices among spouses, partners, caregivers, and/or co-resident family members
Trauma Treatment and Rehabilitation, Including Nonsurgical Orthopedic Conditions	• Prosthetics
	• Prevention and rehabilitation strategies designed to minimize bone loss and prevent heterotopic ossification following amputation
	• Assessment tools that incorporate simultaneous physical and cognitive demands for use in monitoring clinical performance outcomes and return-to-duty status
	• Comparison of the effect of known resuscitation adjuncts, drugs, and biologics via a realistic animal model of hemorrhage and tissue injury with the goal of getting a lifesaving, noncoagulopathic drug into clinical trials and through FDA certification quickly
	• Characterization of oral, maxillofacial, and craniofacial injuries, including treatment needs, prosthetic replacements required, treatment costs, and long-term patient morbidity from combat injuries, and biocompatible craniofacial implants for use in craniofacial reconstruction due to combat trauma

Table 6-1. Detailed Research Gaps in Each Topic Area (cont.)

Topic Area	Research Gap
Trauma Treatment and Rehabilitation, Including Nonsurgical Orthopedic Conditions (cont.)	• Characterization of physical, mechanical, and aesthetic properties of human skin in the subject population ages 17–45
	• Treatments and techniques to prevent and treat penetrating eye injuries
	• Novel rehabilitation techniques, including virtual reality, nonsurgical treatment of extremity injuries (e.g., novel physical therapy techniques), for the mental and physical rehabilitation of other than amputees to facilitate recovery and return to duty
	• Novel approaches for repair and treatment of nerve damage, including nerve regeneration and nerve grafting
	• Surgical and nonsurgical approaches to the treatment of combat-related middle and inner ear trauma, including reconstruction, replacement, or augmentation of hearing structures
Wound Infection and Healing	• Improve wound healing and clinical outcomes by evaluating the role of topical nitric oxide and hyperbaric oxygen to disinfect blast wounds
	• New treatment protocols, drugs, biologics, and devices to reduce wound-related infections and accelerate wound healing
	• Approaches to prevention or treatment of bone infections
	• Methods and technologies for prevention of the formation of bacterial biofilms in wounds and colonization of orthopedic devices
	• Evaluation of oral and topical nutritional supplements and over-the-counter products (e.g., zinc, silver, and lysine) to accelerate wound healing and enhance a patient's immune status
	• Methodologies that will predict clinical outcomes of blast-induced wound infections. Approaches of interest include methodologies to assess total bacterial load in wounds and identification of critical biomarkers that predict outcomes related to wound infection
Wound Infection Vaccines	• FDA-approved vaccines to prevent sepsis caused by gram-negative bacteria
	• FDA-approved vaccines to prevent *Staphylococcus aureus* infection. Priority will be given to those vaccines that also include protection against methicillin-resistant strains.
	• Others as appropriate

In August 2008, the DRMRP released Program Announcements soliciting research proposals in response to three award mechanisms (Table 6-2). These award mechanisms challenged the scientific and clinical communities to develop innovative ideas that will advance the delivery of emerging new approaches, technologies, and agents to the military through basic science, translational, and/or clinical research. A total of 923 proposals were received in response to the FY08 DRMRP Program Announcements.

Table 6-2. DRMRP Funding Mechanisms

Award Mechanism	Key Features
Hypothesis Development Award	Provides support for the initial exploration of innovative, untested, potentially groundbreaking concepts that may lead to promising new products, pharmacologic agents (drugs or biologics), behavioral interventions, devices, clinical guidance, and/or emerging approaches and technologies for deployment-related health care issues within the FY08 DRMRP topic areas. **Funding:** Up to $150,000 for direct costs **Duration:** Up to 18 months
Advanced Technology/ Therapeutic Development Award	Provides support for the assessment of scientific and/or military field deployment feasibility for promising new products, pharmacologic agents (drugs or biologics), behavioral interventions, devices, clinical guidance, and/or emerging approaches and technologies. These awards are expected to yield potential deployment-related health products, approaches, or technologies positioned for human testing. **Funding:** Overall total costs (direct costs plus indirect costs) may not exceed $25M. No more than $5M in total costs will be awarded in any single year **Duration:** Up to 5 years
Clinical Trial Award	Supports rapid implementation of clinical trials with the potential to have a significant impact on a disease or condition addressed in one of the FY08 DRMRP topic areas. All proposed clinical trials must be responsive to the health care needs of deployed members of the Armed Forces and may address prevention, detection, diagnosis, treatment, and/or quality of life. **Funding:** Overall total costs (direct costs plus indirect costs) may not exceed $25M. No more than $5M in total costs will be awarded in any single year. **Duration:** Up to 5 years

Proposal review for all submissions was conducted using a modified version of the USAMRMC two-tier review model recommended by the Institute of Medicine. This two-tier review model has received high praise from the scientific community, advocacy groups, and Congress. The first tier is the scientific peer review of proposals against established criteria for determining scientific merit. For the DRMRP, there is also a concurrent, but separate, military relevance review of proposals against criteria for determining the relevance of the proposed research study to the military community. The Joint Program Alignment Peer Review Panel aligned the results of these two review sessions.

The combined results of these peer review processes were passed along to the Joint Senior Leadership Integration Panel (JSLIP) for the second tier programmatic review. The JSLIP compared proposals to each other and recommended proposals for funding based on the recommendations of the peer review panels, responsiveness to the DRMRP topic areas and research gaps, programmatic relevance, adherence to the intent of the award mechanism, and program portfolio balance. Following programmatic review, those proposals that best fulfill the above criteria and most effectively addressed the unique focus and goals of the program were recommended for funding to the final approval authority, the Deputy Assistant Secretary of Defense for Force Health Protection and Readiness.

Of the 923 proposals received, 44 proposals were recommended for funding and approved by the Deputy Assistant Secretary of Defense for Force Health Protection and Readiness. Additionally, 4 projects were funded from the FY09 PH/TBI Research Program, also administered by USAMRMC Congressionally Directed Medical Research Programs. The FY08 DRMRP investment profile is shown in Table 6-3 by Award Mechanism and in Table 6-4 by Topic Area.

Table 6-3. DRMRP Investment by Award Mechanism

Award Mechanism	Funded/Received	Budget ($M)	Percent Invested
Hypothesis Development Award	28/441	6.2M	6%
Advanced Technology/Therapeutic Development Award	12/371	59.9M	65%
Clinical Trial Award	4/111	26.6M	29%

Table 6-4. DRMRP Investment by Topic Area

Topic Area	Funded/ Received	Budget ($M)	Percent Invested (by $)
Blood Products	1/12	4.8M	5%
Blood Safety	1/15	5.6M	5%
Injury Prevention	3/25	13.2M	12%
Trauma Rehabilitation	4/26	9.3M	9%
Trauma Treatment	10/143	12.3M	11%
Wound Infection Vaccines	1/16	0.9M	1%
Wound Infection and Healing	7/206	7.6M	7%
Psychological Health	7/152	33.4M	31%
Traumatic Brain Injury	10/267	16.4M	15%
Both Psychological Health and Traumatic Brain Injury	4/25	4.3M	4%
Final Development of Medical Devices	0/36	0.0M	0%

Armed Forces Institute of Regenerative Medicine (AFIRM)

OIF/OEF have resulted in more than 5,200 U.S. military fatalities and more than 34,000 injuries. Treatment of combat-related injury and trauma is particularly complex. While advances in body armor have greatly improved torso (vital organ) protection, thereby increasing survivability, those who survive often have more serious injuries than in past military conflicts. Conventional weapons and the destructive force of IEDs ravage face, neck, head and limbs, causing massive trauma and tissue loss.

Regenerative medicine, which has achieved success in the regeneration of human tissues and organs for repair or replacement, represents great potential for treating military personnel with debilitating, disabling, and disfiguring extremity injuries and burns. Regenerative medicine uses bioengineering techniques to prompt the body to regenerate bones and skin as well as organs/tissues, often using the patient's own cells combined with degradable biomaterials. Technologies for engineering tissues are developing rapidly, with the ultimate goal of delivering advanced therapies, such as whole organs and engineered skin, fingers, and limbs. The AFIRM was established to overcome these challenges, expedite transition of technologies, and make regenerative medicine a reality for our wounded warriors.

The AFIRM is a partnership among the USAMRMC, ONR, USAF, NIH, and the VA. It is a world-class, multi-institutional, interdisciplinary network working to develop advanced treatment options for our severely wounded Service men and women. The AFIRM is made up of two civilian research consortia working with the USAISR in Fort Sam Houston, Texas. The Wake Forest University Baptist Medical Center and the McGowan Institute for Regenerative Medicine in Pittsburgh consortium is led by Dr. Anthony Atala and the Rutgers, the State University of New Jersey, and the Cleveland Clinic consortium is led by Dr. Joachim Kohn. Each of these civilian consortia is itself a multi-institutional network. The AFIRM has 114 senior scientists and 116 graduate students and post docs. Current 5-year funding is: U.S. Government ($100M) and State and local matching funds ($68M). In addition, the institutions already have funding from entities such as the NIH for an additional $109M in research projects directly related to the deliverables of the AFIRM.

Vision Center of Excellence (VCoE)

The DoD is collaborating with the VA, academia, and other public and private entities to establish a center of excellence in the prevention, diagnosis, mitigation, treatment, and rehabilitation of military eye injuries. The VCoE will develop, implement, and oversee a data registry for tracking ocular trauma and surgical intervention. It will lead advanced research that defines future clinical practice guidelines, expands rehabilitative programs, and offers new modalities to treat and prevent ocular disease and trauma.

Hearing Center of Excellence (HCoE)

Efforts to establish a joint venture DoD/DVA Center of Excellence in Hearing and Balance dedicated to address the prevention, diagnosis, mitigation, treatment, and rehabilitation of traumatic audiovestibular injury are in progress with the USAF designated as lead agent. This center will work in conjunction with other established centers of excellence commissioned to provide similar leadership in care of the multi-injured warrior and will establish and share registry data to that end.

Accomplishing this mission will involve outreach to academic institutions and industry leaders with expertise in research and development related to prevention, treatment, and rehabilitation of ear-related trauma. HCoE leadership will provide the oversight and education to maintain the highest clinical quality and academic awareness by establishing and promoting best practice guidelines for prevention and treatment, as well as study, develop, and field state-of-the-art technologies related to communication, hearing loss prevention, and hearing restoration.

Traumatic Extremity Injury and Amputation Center of Excellence

The Secretary of Defense and the Secretary of Veterans Affairs are jointly establishing a center of excellence in the mitigation, treatment, and rehabilitation of traumatic extremity injuries and amputations. This "virtual center" will bring together research efforts ongoing at Walter Reed Army Medical Center (WRAMC), Brooke Army Medical Center/Center for the Intrepid, and Naval Medical Center, San Diego, with the goal of collaboratively conducting lines of scientific inquiry aimed at saving injured extremities, avoiding amputations, and preserving and restoring the function of injured extremities. These research programs will focus on advancing treatment options for extremity injuries resulting from deployment-related blast trauma and will include the full range of scientific inquiry encompassing basic, translational, and clinical research.

Military Amputee Research Program (MARP)

The MARP, which includes health care operations at WRAMC, Brooke Army Medical Center/Center for the Intrepid, and Naval Medical Center, San Diego, is a joint system of care that provides full spectrum, state-of-the-art medical, surgical, and rehabilitative treatment for individuals who have experienced limb loss.

The DoD and its extramural partners are conducting research in a number of areas, such as Advanced Prosthetics, Rehabilitation, Outcomes and Program Assessment, Clinical Management, and Database Development and Management. The MARP intramural research program is a multisite, interdisciplinary, collaborative research program. Studies relevant to our active amputee population include, but are not limited to: (1) innovative technologies, such as targeted muscle reinnervation, that enhance prosthetic control; (2) the use of novel pain treatment strategies to reduce the occurrence of phantom limb pain; (3) rehabilitation strategies using immersive virtual reality environments to provide challenging real-life scenarios; (4) functional comparison of available prosthetic technologies (to assist with prosthetic prescription); and (5) validation of instruments used to assess clinical treatment efficacy.

To supplement the intramural work, MARP has also funded extramural projects to advance technologies in the following areas: (1) development of a dynamic socket that conforms to changes in tissue volume of a residual limb; (2) "hardened" prosthetic devices that are resistant to water, dust, and other environmental stressors; (3) powered ankle prostheses that increase function and optimize energy expenditure; and (4) osseointegration to provide innovative solutions for the future.

As we move into the future, it is our goal to build on these advances to meet the continuing need for innovative prosthetic and orthotic development that will lead to optimally functional, durable, and comfortable devices that continue to challenge our patients to achieve their highest goals.

To date, 960 Marines, Soldiers, Sailors, and Airmen have returned from Iraq or Afghanistan with major limb amputations, and many have lost more than one limb. The ultimate goal of the Program is to provide all amputee patients with the opportunity to return to the highest level of physical function possible, and return to active duty if desired. A critical need for continued research efforts to optimize not only amputee care, but other war-related traumatic extremity injuries, led to additional congressional funding in FY09 under the Peer Reviewed Orthopaedic Research Program to expand research efforts to encompass study of both traumatic extremity and amputee injuries.

Center for Neuroscience and Regenerative Medicine (CNRM)

The CNRM is located at the USUHS. This collaborative intramural federal program involving the DoD and NIH was developed to bring together the expertise of clinicians and scientists across disciplines to catalyze innovative approaches to TBI research. The CNRM Research Programs are primarily focused on military patients at WRAMC and National Naval Medical Centers. The USUHS is responsible for the overall operation and management of the CNRM on behalf of the DoD.

The goal of the CNRM is to improve recovery from TBI in military service members and specific objectives are:

- Optimize matching of TBI patients to available treatments. Refine assessment tools to improve inclusion/exclusion criteria and more effectively match patients to treatment plans that are currently available
- Develop TBI treatment outcome measures. Develop a set of assessment tools that can serve as surrogate indicators of clinical outcomes to facilitate evaluation of new and existing treatments
- Design novel therapeutic strategies. Take advantage of preclinical models for mechanistic studies that can inform the design of novel treatments or more effective combinations of existing treatment plans
- Implement clinical applications for military patients across the spectrum of TBI. Identify promising interventional strategies and perform preclinical studies through clinical trials to bring improved treatment options for the range of injuries among military service members

CNRM research efforts have been developed as six research programs designated as: Diagnostics and Imaging, Biomarkers, Neuroprotection, Neuroregeneration, Neuroplasticity, and Rehabilitation and Evaluation. CNRM research programs include investigator-initiated research Projects and Cores, to more effectively support research services across Projects and Programs. The Cores are centralized resources for patient recruitment, patient phenotyping, human imaging, image processing, informatics, biospecimen collection, translational imaging, TBI models, preclinical behavioral assessment, microscopy, and histopathology.

The FY08 Supplemental Funding of $70,000.000 to establish CNRM now supports 57 Projects and 11 Cores involving 54 PIs and approximately 200 Key Personnel. Core plans were developed in user working groups, reviewed through Program Leaders, and reviewed and approved by the CNRM Programmatic Oversight Committee. Projects were developed in user working groups, prioritized through Program Leaders, peer-reviewed by a Technical Review Panel, and reviewed and approved by the CNRM Programmatic Oversight

Committee. An administrative core was also established to support the CNRM research programs.

CNRM collaborative efforts have been developed through a Memorandum of Understanding (MOU) to facilitate interactions between investigators at USUHS, under DoD, and at NIH, under the Department of Health and Human Services. CNRM has also established an MOU with the Armed Forces Institute of Pathology and DVBIC to facilitate analysis of human specimens.

U.S. Army Public Health Command (USAPHC) (Provisional)

The U.S. Army Center for Health Promotion and Preventive Medicine (USACHPPM) provides worldwide scientific expertise and services in clinical and field preventive medicine, environmental and occupational health, health promotion and wellness, epidemiology and disease surveillance, toxicology, and related laboratory sciences. It supports readiness by keeping Soldiers fit to fight while also promoting wellness among their families and the federal civilian workforce. In October 2009, the USAMEDCOM established a provisional USAPHC to coordinate the capabilities of the USACHPPM and the U.S. Army Veterinary Command.

The following summarizes blast-related projects of the USAPHC by program area.

- **Metal Fragment Analysis Program, Directorate of Laboratory Services (DLS)**
  The Assistant Secretary of Defense for Health Affairs (ASD[HA]) and MEDCOM implemented policy requiring laboratory analysis of all fragments removed from wounded service members. The DLS conducts gross alpha and gross beta radioactivity measurements and elemental (metals) analysis via X-ray fluorescence (XRF). The XRF results provide a relative percentage composition for the metals in the fragment. The policy lists metals of interest that are reported. The policy is a result of several research papers that indicated that certain tungsten alloys induced carcinogenesis in a rodent model. The policy requires the laboratory results and subsequent risk assessments be provided to the requesting health care provider as well as be incorporated into a metal fragment database.

  The DLS performs this analysis for requesting Army medical treatment facilities. The Armed Forces Institute of Pathology and the Air Force's lab (formerly Air Force Institute of Operational Health) also provide similar analyses.

- **Deployment Environmental Surveillance Program (DESP), Directorate of Health Risk Management (HRM)**
  The DESP analyzed a sample of debris from the floor of a MRAP vehicle that had been damaged by an IED. The IED struck the MRAP in a section of armored glass resulting in large quantities of fine dust on the inside of the vehicle, some of which stayed airborne for a long period of time. Soldiers working inside the vehicle complained of respiratory irritation following exposure to this dust. The dust was a combination of pulverized glass and the dirt/dust that collects on the inside of vehicles down range. The analysis determined that no long-term effects are expected based on the physical/chemical composition of the dust. The HRM performed this work for the 4th Infantry Division Surgeon's Office.

- **Health Risk Communication Program (HRCP), Directorate of Health Risk Management**
  Due to numerous deployments and the nature of enemy tactics, troops are at risk for sustaining more than one mild brain injury or concussion in a short time frame. This project developed the Health Risk Communication portion of the "VA/DoD Clinical Practice Guideline for Management of Concussion/mTBI—Department of Veterans Affairs and Department of Defense" guidelines as a screening instrument to assist in identifying OEF and OIF veterans who may be suffering from TBI. The guideline will be used by clinicians and medical professionals of the VA and the DoD.

- **Army Hearing Program, Directorate of Occupational and Environmental Medicine (DOEM)**
  The Army Hearing Program conducted a post-deployment noise-induced hearing injury (NIHI) and comorbidity epidemiological study that performed passive surveillance data mining for statistical analyses and time series reporting of prevalence of selected NIHI ICD-9-CM codes that may be markers (sentinel diagnoses) for mTBI and PTSD. NIHI and blast exposure injury codes include acoustic trauma, noise-induced hearing loss, perforated eardrums, tinnitus, dizziness/imbalance problems, and TBI and associated clinical outcomes from TBI including central auditory processing disorder. Prevalence rates were reported to the Military Health System (MHS) and VA health care managers for planning for resources to treat blast trauma veterans.

- **Health Hazard Assessment Program, Directorate of Occupational Health Science**
  An assessment of weapon combustion products from U.S. Army weapons (mortars, missiles, grenades, and explosives) was conducted to support completion of Health Hazard Assessments (HHAs) requested by materiel developers who are creating weapons for the U.S. Army. This is an ongoing effort to analyze data typically collected from U.S. Army Weapons test ranges to determine the risk of injury to the Soldier from occupational exposures to firing weapons and subsequent inhalation of combustion products. This is done by assigning a risk assessment code (RAC) to each event. This program does not evaluate downrange effects of weapons firing. Each combustion product is evaluated individually. Currently, models are being developed to evaluate the combined effects of multiple gases.

Weapon combustion product assessments conducted during FY09:

- Nov 08: M1030 12 Gauge Breaching Cartridge (HHA): Given the use scenario provided, no inhalation hazards associated with the use of the M1030 12 Gauge Breaching Cartridge were identified in the HHA.

- Nov 08: XM104 Non-Lethal Bursting Hand Grenade (HHA): Given the use scenario provided, no inhalation hazards associated with the use of the XM104 Non-Lethal Bursting Hand Grenade were identified in the HHA.

- Feb 09: M855LFS, 5.56 Millimeter, Ball, Lead Free Slug, Cartridge (HHA): This was an initial HHA and, although combustion products were identified as potential hazards, no data were available for assessment.

- May 09: AT4-Confined Space-Tandem Warhead Light Anti-Armor Weapon System (AT4-CS-TW) (HHA): Exposure to weapon combustion products was identified as a medium-risk hazard (RAC 3, HS III, HP B). Recommendations included limiting personnel exposures within a firing enclosure to no more than three successive shots per day based on maximum allowable consecutive exposure calculations and ensuring that user and training documents identify this requirement. A residual RAC of 4 (HS III, HP D) was assigned for compliance.

- May 09: M829E4, 120-millimeter, Armor-Piercing Fin-Stabilized Discarding Sabot-Tracer, Advanced Kinetic Energy Cartridge (HHA): this was an initial HHA and, although combustion products were identified as potential hazards, no data were available for assessment.

- **Ergonomics and Health Hazard Assessment Program, Directorate of Occupational Health Science**

An ongoing effort to analyze data typically collected from U.S. Army weapons test ranges to determine, by assigning a RAC, the risk of injury to the lung from occupational exposures to blast. This includes exposures to blast realized by gun crews and other personnel firing weapons. This assessment program has been active at the USAPHC (provisional) since 2002.

Assessments of blast exposure from weapons conducted during FY09:

- Sep 09: XM1061 (U.S. Army): The purpose of this test was to estimate the negative health impacts to the lung from blast sustained by XM1061 mortar gun crews launching mortars. BOP not reported as data revealed the exposure would not impose significant risk to Soldier operators.

- Aug 09: Special test (Non-HHA, Non-DoD): The purpose of this test was to estimate the negative health impacts to the lung from blast sustained by an occupant in an enclosure when an explosive device, simulated by a specified quantity of composition C-4 moldable explosive, was detonated.

- Jun 09: Tube-launched, optically tracked, wire-guided (TOW) missile Tube-launched, Improved Target Acquisition System (ITAS) (U.S. Army): The purpose of this test was to estimate the negative health impacts to the lung from blast sustained by a gunner launching a TOW missile from the MRAP.

- May 09: 120MM Multi-Purpose High Explosive (MPHE) (USMC): The purpose of this test was to estimate the negative health impacts to the lung from blast sustained by the gun crew firing a 120MM MPHE round from inside a tank.

- **Laser/Optical Radiation Program (L/ORP), Directorate of Occupational Health Science**
  Members of the L/ORP have developed a measurement technique to assess hazards to the eyes and skin from the optical radiation emitted by explosive devices (e.g., retinal injuries resulting in blindness or burns to the skin). Inexpensive passive detectors, designed and used for more than 20 years, can evaluate hazards to the skin and eye without the use of electronics, however, are susceptible to acoustic and electromagnetic interference.

  The L/ORP devised a technique that can be used to make reliable radiometric measurements of optical radiation sources, including exploding devices, which limit the number of parameters that must be specifically measured. The results of this technique have been compared to traditional spectro-radiometric measurements made in the L/ORP laboratory on a variety of continuous wave sources and have agreed within a reasonable error.

  Work is under way to model the source temperature of an exploding device from its chemical content. Measurements from exploding sources are being compared to the mass of the exploding material to determine if a precise theoretical hazard analysis is possible from knowledge of only the chemical composition and mass. The outcome looks favorable but more measurements are needed to confirm the theory.

- **Injury Prevention Program, Directorate of Epidemiology and Disease Surveillance**
  The Injury Prevention Program is currently working on a Deployment Injury Surveillance project. This project provides ongoing injury surveillance (battle and non-battle injuries) for deployed Soldiers using medical, air evacuation, casualty, and safety data systems. Annual deployment injury surveillance reports are prepared describing injury rates, types, causes, and anatomic distributions for battle and non-battle injuries. Battle and non-battle injury rates are compared over time and for different phases of the ongoing operations. A unique and primary objective of this project is to identify and classify the causes of injury that may be preventable. This is the only project within DoD that is able to report specific injury causes for non-battle injuries. A draft report has been completed describing the incidence and causes of TBI from 2004 to 2008 that were hospitalized either in CENTCOM or air evacuated from CENTCOM.

Chapter 7

KEY BLAST INJURY RESEARCH ISSUES

Blast Injury Prediction Tool Assessment Process (BIPTAP)

An important EA responsibility is to identify blast injury prevention and treatment standards and to recommend appropriate standards to the ASD(HA) for approval and DoD-wide implementation. Blast injury prevention standards include design guidelines and performance criteria for personal and vehicle crew protection systems. Blast injury treatment standards include clinical practice guidelines. Table 7-1 shows responsibilities assigned in DoDD 6025.21E, with the responsibilities for recommending and approving blast injury prevention and treatment standards highlighted in yellow.

Table 7-1. Program Responsibilities Under DoDD 6025.21E

Responsibilities and Functions	DDR&E (ASBREM Chair)	ASD(HA) (ASBREM Co-Chair)	SECARMY	SECNAV & SECAF	USUHS	CJCS	USSOC	JIEDDO
Oversee EA	✔							
Approve Blast Injury Research Programs	✔							
Ensure new technology is transitioned to DoD Components	✔							
Assist in requirements development and needs assessments	✔	✔		✔			✔	✔
Approve blast injury prevention, mitigation & treatment standards		✔						
Ensure MHS information systems support the EA		✔						
Program, budget, and execute DDR&E approved program			✔					
Support joint database for improving protection systems (JTAPIC)			✔					✔
Recommend blast injury prevention, mitigation & treatment standards			✔					
Appoint ASBREM Reps			✔	✔	✔	✔	✔	✔
Coordinate all blast-injury efforts and requirements through the EA				✔	✔	✔	✔	✔

There are four key components that comprise a blast injury prevention standard; these are valid human effects models, simulation software to run those models, assessment methodologies for using the simulations to evaluate protection systems, and policy thresholds of minimum acceptable protection, or maximum acceptable risk of injury. Each component is critical to the success of a blast injury prevention standard, but valid human effects models and available, user-friendly software applications form the foundation on which the standard is built. 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.

To carry out the EA's responsibility to recommend blast injury prevention standards, the PCO has obtained support from the JHU/APL to develop an impartial process for identifying and critically assessing candidate blast injury prediction tools. These tools that comprise the first two key components of a blast injury prevention standard, together with appropriate assessment methodologies and minimum acceptable protection guidelines can be implemented as DoD blast injury prevention standards.

The process that JHU/APL has developed is called the BIPTAP. The BIPTAP is designed to identify and critically evaluate available blast injury prediction tools and to recommend the best available tools that may be considered for implementation in a DoD blast injury prevention standard. The major components of the BIPTAP are a systematic literature review to identify relevant injury prediction tools; establishment of a broad-based, nonadvocacy, independent review panel; conduct of panel meetings to establish injury prediction tool review criteria; and in-depth reviews of candidate injury prediction tools by the panel. Figure 7-1 shows how the BIPTAP relates to the components of a blast injury prevention standard.

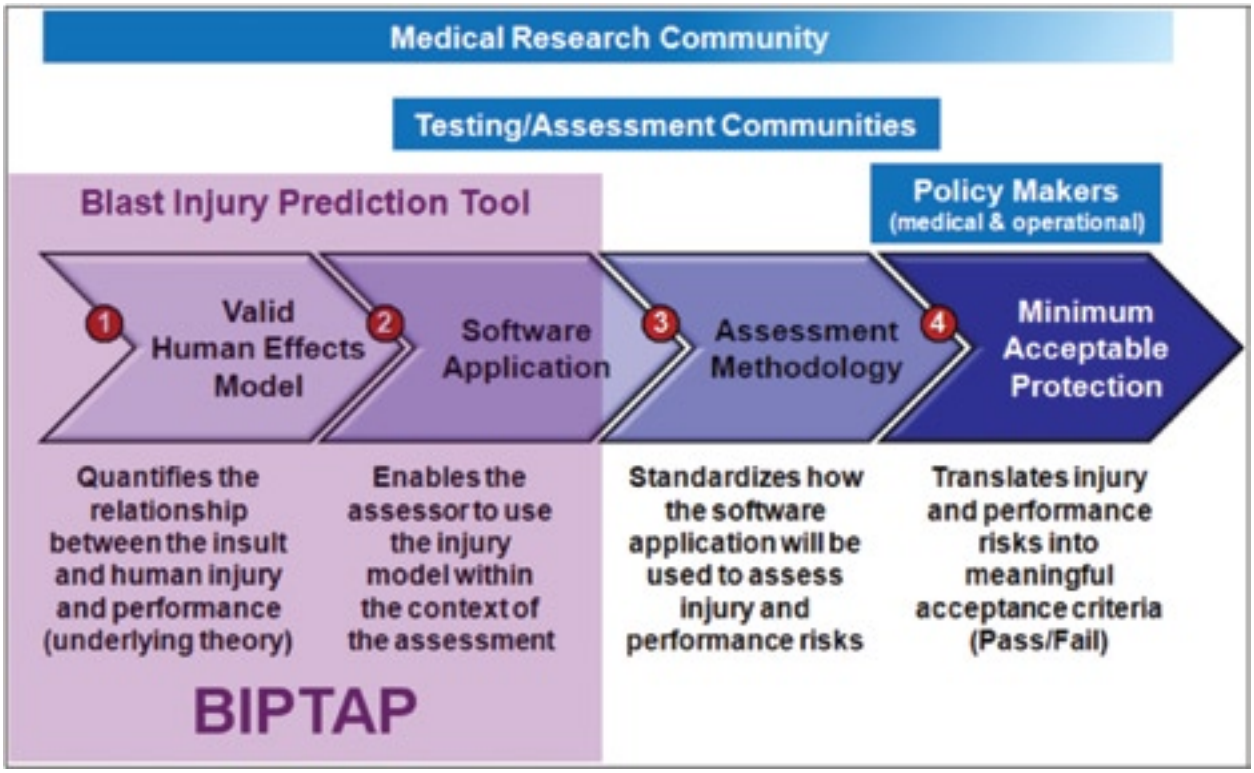


Figure 7-1. Four Key Components of a DoD Blast Injury Prevention Standard

The initial implementation of the BIPTAP focused on a class of injury prediction tools that predict injury and performance outcomes from inhalation exposures to mixed fire gases. 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.

The BIPTAP used a literature review to identify relevant inhalation injury and performance prediction tools. Three candidate tools were identified: the Airways Breathing Casualty (ABC) model, the EXODUS model, and the TGAS. Following the identification of the candidate tools, a panel of subject matter experts was established to evaluate the tools. This expert panel, comprising eight members from the DoD, industry, and academia, was co-chaired by representatives from JHU/APL and the office of the Director, Operational Test and Evaluation.

During the evaluation, the expert panel assessed each candidate tool using background information and a set of criteria. The background information included materials found during the literature review, completed tool assessments provided by model developers, model user manuals, and past model verification and validation results. Panel members reviewed these materials and used them to support recommendations regarding the suitability of the candidate tools for implementation in DoD standards.

The review process culminated with a conference that took place in February 2010. During this conference, the expert panel had the opportunity to question tool developers on the details of their models/tools and to solicit additional information. After the conference, the panel produced an assessment report on the results of its analyses with recommendations to the PCO.

The panel recommended that the ABC model should not be considered further while TGAS and EXODUS should be considered for further evaluation. The panel also recommended a further examination of TGAS and EXODUS with model runs using specific test cases. The PCO is working with JHU/APL to implement this recommendation for further examination of TGAS and EXODUS. The performance of these tools will be assessed for specific test cases representing the following intended uses:

- Personnel vulnerability or survivability assessment during and after an exposure(s)
- Personnel performance assessments during and after an exposure(s)
- Performance standards development for design and evaluation of protection equipment or techniques
- Planning and analysis of tests for personnel survivability assessments
- Occupational exposure standards development for health risks related to weapon system exposure(s)
- Casualty estimation in support of medical planning

A detailed technical report describing the BIPTAP and this first implementation of BIPTAP to assess toxic (fire) gas inhalation tools will be published in FY11. The PCO is currently developing a staffing process that will be used to staff a final recommendation to ASD(HA) for approval. The PCO is also exploring processes to address the last two components—assessment methodology and minimum acceptable protection—of the blast injury prevention standard.

Helmet Mounted Sensor System (HMSS)

The former VCSA directed the fielding of HMSS to two deploying Brigade Combat Teams (BCTs). The PM Soldier Protective Equipment (PM SPE) fielded 6,979 HMSS to the 1st BCT, 4th ID (OIF) and 4th BCT, 101st ABN (OEF) between Dec 07 and Feb 08. Additionally, the USMC's Program Manager, Infantry Combat Equipment (PM ICE) fielded 1,952 HMSS to 2 deployed Marine Battalions.

The objective of these fielding initiatives was 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 Soldiers needing medical evaluations for head injuries. Two HMSS variants were fielded, one mounted externally on the back of the Advanced Combat Helmet and the other mounted internally in the crown. The HMSS records helmet acceleration and pressure from impacts and explosions.

The JTAPIC Program, in partnership with the PM SPE and PM ICE, led a three-phased HMSS data analysis project. The JTAPIC data analysis project team included the 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 with actual injuries.

- **Findings of the HMSS Data Analysis Project**

  In Phase I of the HMSS data analysis project, extensive laboratory tests of combat helmets with HMSS were conducted to assess HMSS reliability and accuracy and to develop a helmet/head transfer function (Figure 7-2). Although the sensor testing revealed HMSS performance problems and data artifacts, information derived from the HMSS and laboratory-grade helmet sensors made it possible to develop a mathematical model that can reliably estimate acceleration-caused concussion "doses" using raw HMSS data. This model was leveraged from previous head impact and helmet modeling work funded by ONR and the NHTSA.

  Phase II focused on evaluating the data from the fielded HMSS. The research team developed data screening tools to analyze nearly 250,000 events that were downloaded from the HMSS. These screening tools made it possible to quickly distinguish between "good" and "bad" HMSS acceleration data and to identify data anomalies that made it impossible to interpret the pressure data. In this Phase, the team also calculated head doses from the HMSS data using the model developed in Phase I. These calculated doses were then compared with existing and widely recognized concussion criteria. The team found that the doses were well distributed, with the majority of doses indicating a low risk of concussion, and a very small percentage of doses (~0.5%) indicating a high risk of concussion. These findings provided a "sanity check" on the quality of the HMSS acceleration data.

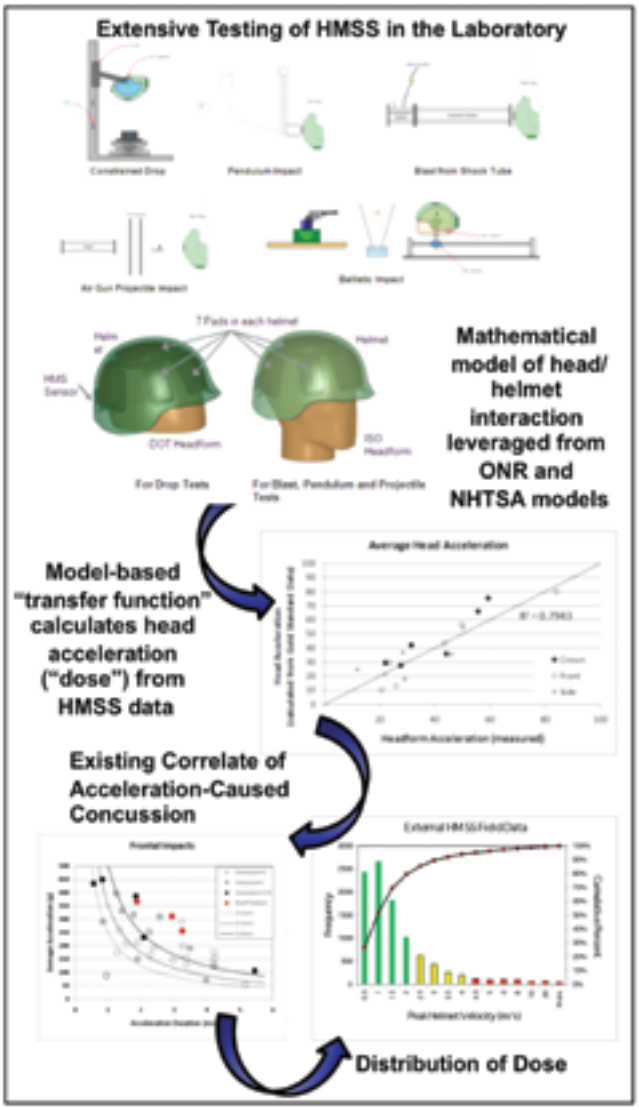


Figure 7-2. Generation I HMSS data analysis

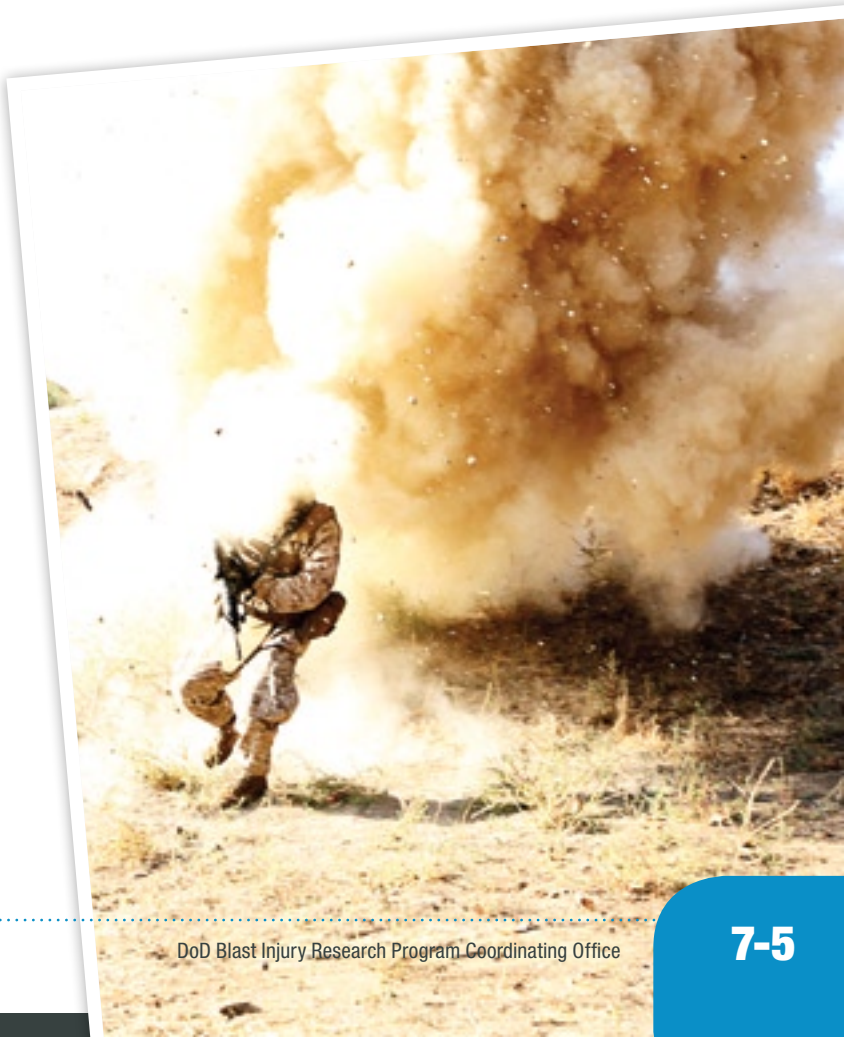
The objective of Phase III was to determine if head impact doses calculated from HMSS data correlated with head injuries sustained by the HMSS-wearing population of deployed Soldiers and Marines. Phase III was a two-tiered effort with the first tier focused on individuals who suffered acute head injuries in theater, and the second focused on individuals who reported less severe head injury symptoms during post deployment that were attributed to head impacts during the deployment.

In the first tier of the Phase III effort, NHRC used tactical record data, theater unit medical logs, and Defense Casualty Information Processing System data to identify individuals with head injuries. They identified 61 individuals with head injuries among the deployed HMSS-wearing population of Soldiers and Marines. Among these, only two had HMSS data recorded within one day of the reported injury. This sample was too small to draw conclusions about the correlation of HMSS data with acute head injuries. Many factors hindered the team's ability to match HMSS data records with acute head injury data. HMSS performance problems led to a low percentage of usable data. Errors in entering battle roster numbers and starting dates/times into the HMSS made it difficult to match HMSS with the individuals who wore them and to match HMSS record dates with injury dates. Unit compliance with HMSS downloading requirements was problematic. Army HMSS download records showed good compliance early in the deployment, but few HMSS were downloaded later in the deployment. Marine compliance was much better, with more than 90% of the HMSS downloaded at the end of the deployment; however, most of the data from these downloads were recorded early in the deployment indicating possible HMSS data loss problems.

The second tier of the Phase III effort attempted to correlate HMSS data with less severe head injuries reported during post deployment in a population of Soldiers being treated at Fort Campbell. Fifteen HMSS-wearing Soldiers were identified in the Fort Campbell database. Only one of these had an exposure profile that was statistically different from the noninjured population. There were no statistically significant differences in the exposure profiles between the remaining 14 Soldiers and the noninjured population.

- **Conclusions**

  The 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 Generation II HMSS only if all lessons learned from the first-generation HMSS are applied. The PM SPE has initiated actions to acquire, test, and field the Generation II HMSS. The JTAPIC data analysis team will support this effort.



DoD Brain Injury Computational Modeling Expert Panel

Our current understanding of the existence and mechanisms of non-impact, blast-induced mTBI is very limited. There are several hypotheses of the brain injury mechanisms caused by blast including: blood vessel tearing and hemorrhage, mechanical or immune caused breakdown of the blood brain barrier, vasospasm, air emboli, microcavitation, diffused axonal injury, vasogenic and cytotoxic edema, local ischemia/hypoxia, oxidative stress and reactive oxygen species, mechanical misalignment of synapses and synaptic plasticity, Ca++ flooding and neuroexcitation, and deregulation induction of apoptotic and necrotic pathways. The conventional approaches of animal testing, in vitro study, 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 TBI injury hypotheses. Physiology-based mathematical modeling tools of blast-induced head injury may provide a framework to understand injury mechanisms, guide experimental testing, interpret the data, and scale animal data to humans to study the injury mechanisms and effectiveness of protective or treatment strategies.

Until very recently high-fidelity computational modeling of blast brain injury has not been studied. Modeling blast TBI and resulting trauma is extremely difficult as it involves a range of disciplines such as gas and structure dynamics, biomechanics, physiology, pathology, biology, biochemistry, time and space scales. In the last 2 to 3 years visible progress has been achieved in DoD-sponsored models as highlighted in Chapter 4. Most of these efforts are unique and represent novel distinct approaches. In addition, existing software tools and computational models of TBI still have several limitations, and there are some major challenges to be solved in blast wave brain TBI models.

In a proactive effort, the PCO established the DoD Brain Injury Computational Modeling Expert Panel 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 (e.g., Department of Transportation and NIH)
- Accelerate transition of preventive and treatment strategies

The first DoD Brain Injury Computational Modeling Expert Panel was attended by over 25 subject matter experts from the DoD, the Departments of Energy, Transportation, and Veterans Affairs, academia, industry, and the Republic of Singapore. The Expert Panel developed a working definition and felt that an ideal validated computational model of mTBI should be anatomically and pathophysiologically correct (i.e., biofidelic model), exhibit consistent material and biological properties, answer the problem as proposed, be based on experimental data using animal models, be field consistent, 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) and have the ability to capture empirical data. It was noted that the potential limitations of the model should be clearly defined and consider the systemic effects of blast in Soldiers.

In addition, the panel assembled the following list of challenges related to computational modeling of brain injury:

- Developing validated constitutive models for material properties of skull, CSF, and brain tissue, particularly for large strain rates and for perfused tissue
- Developing mechanical dose-response models of brain tissue dysfunction

- Solving brain biomechanics equations using FE method solvers for soft tissue (overcoming numerical difficulties)
- Simulating long-time transient brain biomechanics during secondary injury development (e.g., edema, hematoma, and herniation)
- Modeling impact (obtaining the correct parameters for contact and friction) between brain and cranium
- Developing benchmarks for modeling brain-CSF-cranium interaction (fluid-structure interaction capability required)
- Determining how to properly account for the presence of large cerebral blood vessels, bridging veins, and brain perfusion
- Developing adequate models of tissue mechanical injury (material failure)
- Establishing linkages to neurobiology
- Developing benchmark experiments
- Modeling soft tissue
- Developing criteria for animal models that reproduce injury (determining endpoints)
- Understanding how mechanical energy translates into a concussion
- Exploring the issue of cavitation
- Coupling whole body and the brain
- Understanding thresholds for injury (e.g., determine whether closed head-injury thresholds for TBI in civilians can be applied to mTBI)
- Establishing solid models across multiple geometric scales
- Developing an objective method to measure blast exposure

The PCO anticipates that this focused effort will be the first step in leveraging and intergrating results of individual projects to generate a unified solution that may result in development and validation of accurate computational models of blast-induced TBI. These models would expedite prevention and treatment strategies for blast-related TBI by providing a framework for understanding injury mechanisms, guiding experimental testing, interpreting data, and scaling animal data to humans.

Recovery of Historical Blast Injury Research Data

Over a decade ago, the Military Operational Medicine Research Program (MOMRP) at USAMRMC salvaged the original data from an extensive blast injury research program that took place at the Blast Test Site located on Kirtland Air Force Base in Albuquerque, New Mexico, from 1951–1998. This blast injury research program is generally recognized as the world's most extensive. It included a vast number of experiments under a wide range of blast conditions with more than 13 animal species. Most of these types of experiments can never be done again under current laws and regulations governing the ethical use of animals in research. The recovered data consist of original laboratory notebooks, sensor recordings, and necropsy photos that are housed in a temperature-controlled environment at the L-3 Communications/Jaycor facility in San Diego, California.

A recent 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 illustrates the tremendous value of these historical blast injury research data. Military working dogs are suffering blast wounds in theater, and questions have arisen from vets in the field about initial symptoms, expected injury progression, how long to monitor, what to look for when monitoring, and recommended treatment. The Directors needed information that could help the vets improve outcomes, but there is a paucity of this information in the current veterinary literature. To answer these questions, the PCO reviewed historical blast injury research data from a searchable literature database of reports, papers, etc. from the Albuquerque site. They searched this database and found 35 documents that contain information on dogs. After reviewing these documents, they identified one, authored by Richmond and White (1962), that contained answers to many of the Directors' questions. It described the susceptibility of dogs to blast injury and lethality, post-blast survival times, possible injury mechanisms, and an extensive list of observed symptoms. The response to this request for information illustrates the value of the blast injury research archive in providing answers to current problems without having to conduct new animal research.

The PCO recognizes the tremendous value of these historical blast injury research data and is actively seeking opportunities to obtain funding support to recover these data in a format that can be used by researchers to solve current and future blast injury problems. Recently, the Personnel Protection Subgroup of the TSWG, CTTSO requested the PCO's help in solving a Navy blast problem that will provide another opportunity to demonstrate the value of the historical blast injury research data.

The Navy's survivability assessment community needs a tool to assess crew survivability for a unique shipboard blast condition known as a quasi-static pressure (QSP) condition. This condition occurs in crew compartments that are near but not directly affected by an explosion.

Under QSP conditions, there is no shock front, but the pressure rises fairly quickly (over tens of milliseconds) as the high pressure gases fill the compartment. The Navy is interested in using the USAMRMC's blast lung injury prediction model known as "INJURY 8.2" but they want some assurance that this model is valid for QSP conditions.

Again, the PCO turned to the historical blast injury research data to address the Navy's problem. These data include studies that dealt with blasts that leak into bunkers and foxholes. These are the kinds of situations that produce the slow rising blast conditions that are representative of QSP conditions. The PCO proposed and TSWG agreed to fund a project to validate the INJURY 8.2 model using these historical data. The contractor will first locate and digitize the original test reports and data from these particular studies. Then, they will determine the test conditions and use mathematical simulations to reconstruct the blast conditions. Finally, they will use the blast condition and animal injury data to validate the INJURY 8.2 model. This 9-month project began in June 2010.

If this project is successful, it will solve a Navy blast problem without the need for new animal injury studies that are costly, time consuming, and difficult to do in an era of stringent rules for the use of animal research subjects. It will also prevent duplication of effort by leveraging an existing Army tool for a Navy application.

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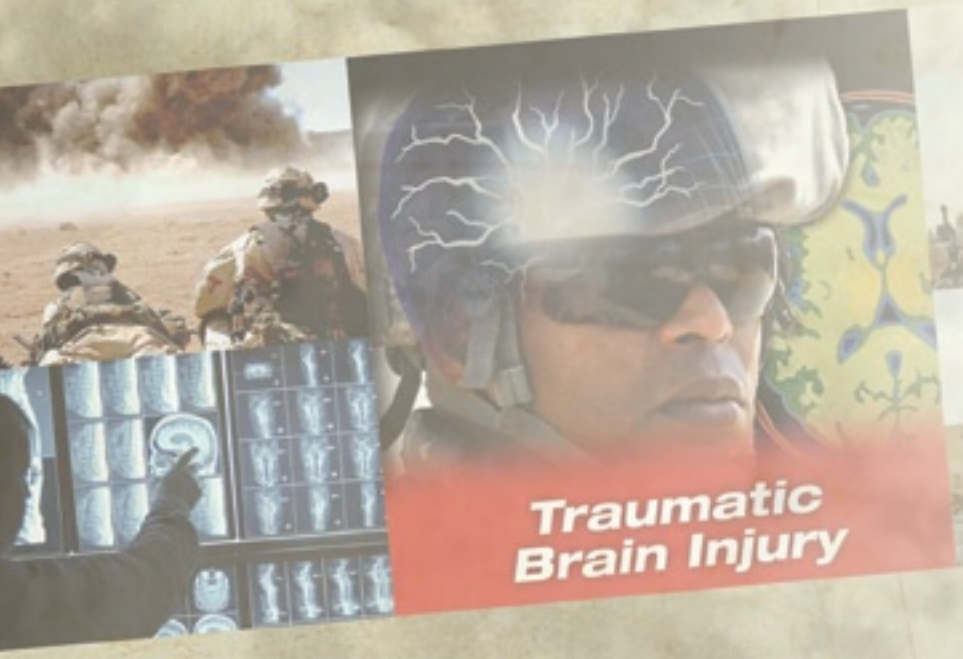
Meeting on

Non-Impact, Blast-Induced Mild Traumatic Brain Injur



May 12–14, 2009

Hyatt Dulles, Herndon, VA

Chapter 8

STATE-OF-THE-SCIENCE MEETINGS 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 us determine what is known and what is unknown about a particular blast injury topic. These meetings are designed to bring in top researchers, worldwide, from academia, DoD, other government organizations, and industry to share their expertise in helping us 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 provide vital evidence needed to prevent, mitigate, and treat blast-related injuries.

Non-Impact, Blast-Induced Mild Traumatic Brain Injury

The DoD Blast Injury Research PCO, in coordination with the DCoE for PH/TBI, hosted the 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.

The meeting was attended by over 75 experts representing the DoD, the Department of Transportation, the VA, academia, and industry. Countries represented at the meeting included Canada, Japan, the Netherlands, Sweden, and the United States.

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 in the DoD Blast Injury Research Program. This gap consists of two questions: (1) Does non-impact, blast-induced mTBI exist? (2) If it does exist, what is the injury mechanism? Understanding the mechanism of any injury is the key to developing effective prevention, mitigation, and treatment strategies.

The DoD Blast Injury Research Program portfolio contains 40 projects, totaling $34M, that are addressing these questions. Among these projects are the DARPA "PREVENT" program and the Massachusetts Institute of Technology (MIT)/ Institute for Soldier Nanotechnology project on "Tissue-Level Mechanisms of Blast Injury." The performers of these research projects include DoD laboratories, other federal agencies, academia, and industry.

These projects are investigating many possible causes for a non-impact, blast-induced mTBI, including a blast-induced surge in the vascular system, direct effects of the blast pressure wave on the brain tissue, head acceleration, electromagnetic pulse, thermal effects, and inhaled toxic gases. So far, there are no conclusive data from any of these ongoing projects that confirm the existence or mechanisms of this type of injury. Without conclusive data, it would be unwise to modify existing protection systems, such as body armor and combat helmets, because uninformed modifications of protection systems can have disastrous results.

Figure 8-1. Panel Members

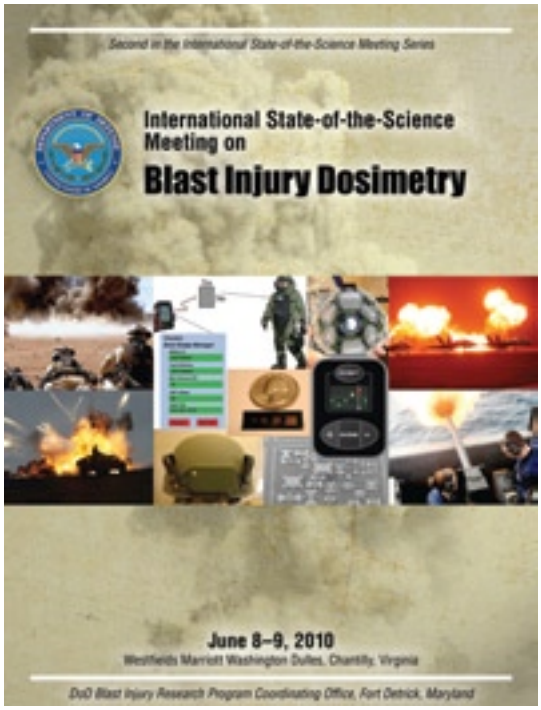
Findings:

- The current working definition of mTBI does not meet the needs for clinical assessment of brain injury.
- There is evidence from clinical and animal studies that non-impact, blast-induced mild trauma to the brain can occur; however, there are many limited clinical data that support the existence of this injury. There are extensive animal data; however, scaling and exposure conditions temper the relevance of these data to human injuries.
- There is 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. Blast insults include shock waves, toxic gases, thermal injuries, electromagnetic pulses, and acceleration. Biophysical responses include biomechanical (e.g., strain rates, stresses, and flexures), chemical, vascular surge, cavitation, and shock wave-induced piezoelectric electromagnetic alterations. Physiological responses include vasospasm, hemorrhage/micro-bleeds, ICP, neuronal damage (synaptic, dendritic, cell body), inflammatory responses, and alterations in neurotransmitters.
- There are insufficient data on the nature of non-impact, blast-induced mTBI to make recommendations on how to better protect Soldiers. Hence, there is a need to assess and leverage neurobiological, neurobehavioral, and biophysical research funded by the DoD's TBI/PTSD program and other federal programs that pertain to this topic.
- The knowledge gaps identified regarding the association between non-impact blast exposure and mTBI included:
  - Components and thresholds of a blast responsible for the insult and injury.
  - Clinical correlates associated with non-impact blast exposure.
  - Validated computational and analytic models.
  - Neuropathological data surrounding blast injury in humans.
  - Sharing of data across research entities.
  - Recovery of historical blast injury research data.
  - Scientifically informed protection, prevention, and treatment strategies 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 Summary of Meeting Proceedings is posted on the DoD Blast Injury Research Program web site at https://blastinjuryresearch.amedd.army.mil/index.cfm?f=application.news. A sampling of the research presented at this meeting will be published in a special issue of *NeuroImage*.



Blast Injury Dosimetry (Objective Measures of "Blast Exposure")

The Blast Injury Research PCO held a planning meeting to develop and prioritize topics for future state-of-the-science meetings. Present at the meeting were representatives from the DCoE for PH/TBI and the JTCGs 5, 6, and 8 (Military Operational Medicine, Combat Casualty Care, and Clinical and Rehabilitative Medicine, respectively). The group selected "Blast Injury Dosimetry" as the topic for the second State-of-the-Science meeting.

This meeting was held on June 8–9, 2010 in Chantilly, Virginia and 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. 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 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.

A Summary of Meeting Proceedings is posted on the DoD Blast Injury Research Program website at https://blastinjuryresearch.AMEDD.Army.mil/index.cfm?f=Application.News.

Appendix A:
ACRONYMS

2-, 3-D	Two-, Three-Dimensional
ABC	Airways Breathing Casualty
ADMA	Asymmetric Dimethyl Arginine
AFIRM	Armed Forces Institute of Regenerative Medicine
AIS	Abbreviated Injury Severity Scale
ARL	Army Research Laboratory
ASA(ALT)	Assistant Secretary of the Army (Acquisition, Logistics, and Technology)
ASBREM	Armed Services Biomedical Research Evaluation and Management (Committee)
ASD(HA)	Assistant Secretary of Defense for Health Affairs
BAA	Broad Agency Announcement
BABTA	Body Armor Blunt Trauma Assessment
BCTs	Brigade Combat Teams
BIPTAP	Blast Injury Prediction Tool Assessment Process
BOP	Blast Overpressure
CC	Cognitive Control
CCCRP	Combat Casualty Care Research Program
CJCS	Chairman of the Joint Chiefs of Staff
CNRM	Center for Neuroscience and Regenerative Medicine
CNS	Central Nervous System
COBIA	Cranial-Only Blast Injury Apparatus
CSF	Cerebral Spinal Fluid
CTTSO	Combating Terrorism Technical Support Office
DARPA	Defense Advanced Research Projects Agency
DCoE	Defense Centers of Excellence
DEKs	Drivers Enhancement Kits
DESP	Deployment Environmental Surveillance Program
DLS	Directorate of Laboratory Services
DRMRP	Deployment Related Medical Research Program
DoD	Department of Defense
DoDD	DoD Directive
DOEM	Directorate of Occupational and Environmental Medicine
DTI	Diffusion Tensor Imaging
DVBIC	Defense and Veterans Brain Injury Center
EA	Executive Agent
FDA	U.S. Food and Drug Administration
FDP	Freeze Dried Platelets
FY	Fiscal Year
HBCT	Heavy Brigade Combat Team

HCoE	Hearing Center of Excellence
HHA	Health Hazard Assessment
HMSS	Helmet Mounted Sensor System
HRCP	Health Risk Communication Program
HRM	Directorate of Health Risk Management
IAN	Incident Analysis Network
ICD	International Classification of Diseases
ICP	Intracranial Pressure
IED	Improvised Explosive Device
IIPT	Integrating Integrated Product Team
IND	Investigational New Drug
IPAN	Injury Prevention Analysis Network
ITD-7	Impedance Threshold Device with 7 cm H_2O Resistance
JDMS	JTAPIC Data Management System
JHU/APL	Johns Hopkins University Applied Physics Laboratory
JPCs	Joint Program Committees
JSLIP	Joint Senior Leadership Integration Panel
JTAPIC	Joint Trauma Analysis and Prevention of Injury in Combat
JTCGs	Joint Technology Coordinating Groups
KIA	Killed In Action
L/ORP	Laser/Optical Radiation Program
MARP	Military Amputee Research Program
MDD	Major Depressive Disorder
MHS	Military Health System
MRAP	Mine Resistant Ambush Protected
MOU	Memorandum of Understanding
mTBI	mild Traumatic Brain Injury
NCS	Non-Convulsive Seizure
NHRC	Naval Health Research Center
NHTSA	National Highway Traffic Safety Administration
NIH	National Institutes of Health
NIHI	Noise Induced Hearing Injury
OAFME	Office of the Armed Forces Medical Examiner
OCO	Overseas Contingency Operations
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
ONR	Office of Naval Research
ORCA	Operational Requirement-Based Casualty Assessment
PBBI	Post-Blast Brain Injury
PCS	Post-Concussive Syndrome
PCO	Program Coordinating Office
PH/TBI	Psychological Health and Traumatic Brain Injury
PI	Principal Investigator
PM ICE	Program Manager, Infantry Combat Equipment
PM SPE	Product Manager, Soldier Protective Equipment
PM SPIE	Project Manager, Soldier Protection and Individual Equipment

PMO	Program Management Office
POM	Program Objective Memorandum
PPE	Personal Protective Equipment
PTSD	Post-Traumatic Stress Disorder
QSP	Quasi-Static Pressure
RAC	Risk Assessment Code
RBC	Red Blood Cell
RFI	Request for Information
SLAD	Survivability/Lethality Analysis Directorate
TBI	Traumatic Brain Injury
TGAS	Toxic Gas Assessment Software
TSWG	Technical Support Working Group
TTP	Tactics, Techniques, and Procedures
USAARL	U.S. Army Aeromedical Research Laboratory
USACHPPM	U.S. Army Center for Health Promotion and Preventive Medicine
USAISR	U.S. Army Institute of Surgical Research
USAMEDCOM	U.S. Army Medical Command
USAMMDA	U.S. Army Medical Materiel Development Activity
USAMRMC	U.S. Army Medical Research and Materiel Command
USAPHC	U.S. Army Public Health Command (Provisional)
USUHS	Uniformed Services University of the Health Sciences
VA	Department of Veterans Affairs
VCoE	Vision Center of Excellence
VCSA	Vice Chief of Staff of the Army
WIA	Wounded In Action
WRAIR	Walter Reed Army Institute of Research
WRAMC	Walter Reed Army Medical Center
WSU	Wayne State University
XRF	X-ray Fluorescence

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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