Chapter 7

IMPACT OF BODY ARMOR ON HEAD AND NECK INJURIES: PREVENTIVE MEASURES

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INTRODUCTION

BODY ARMOR FROM THE AMERICAN CIVIL WAR THROUGH WORLD WAR I

CURRENT US MILITARY BODY ARMOR

BODY ARMOR IN LAW ENFORCEMENT

WHY MORE CASUALTIES ARE SURVIVING
- **Squad-Level Care**
- **Better Combat Medic Training**
- **Joint Medical Training**
- **Improved Airway Management and Hemorrhage Control**
- **Greater Availability of a Variety of Blood Products**
- **The Lethal Triad**
- **Medical Evacuation and Forward Placement of Surgeons**
- **Airborne Intensive Care Units**
- **Process Improvement**

EVIDENCE-BASED REVIEW

INFECTIOUS DISEASES ASSOCIATED WITH HEAD AND NECK INJURIES

FUTURE DIRECTIONS
- **The Joint Trauma Analysis and Prevention of Injury in Combat Program**
- **Improving Hemorrhage Control**
- **Adapting Existing Technologies to Wartime Injuries**
- **Improved Ballistic Protection of the Face and Eyes**
- **The "Iron Man" Suit**
- **Novel Materials**
- **The Defense Health Agency**

SUMMARY

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INTRODUCTION

Combatants have been trying to mitigate the effects of enemy spears, arrows, gunshots, projectiles, missiles, and fragments throughout the history of warfare, marked by cycles of advances in protection, which are then surpassed by more lethal offensive weapons, followed by advanced protection against the newer weapons. During these cycles, expensive protection used by highly trained personnel was often penetrated by weapons wielded by relatively untrained personnel. Thus, total body armor (very expensive) for knights (who took years to train) generally offered protection against maces, flails, and swords, but did not protect the combatant from crossbows. Crossbows, easy to operate by a relatively untrained peasant, could kill a knight in full armor but allowed a rate of fire of only two bolts per minute. The situation became even worse for the knight with the advent of the longbow. A skilled longbow operator could accurately fire ten to twelve arrows per minute and pierce a knight's armor at a range of 250 yards. A modern-day example is a relatively untrained Iraqi insurgent using a crude improvised explosive device (IED) to destroy a $3 million Bradley fighting vehicle and maim or kill the occupants. Compounding the use of protection has been the tradeoff between the combatant's mobility, maneuverability, and comfort and the personal armor's ability to negate the effect of an employed weapon.

BODY ARMOR FROM THE AMERICAN CIVIL WAR THROUGH WORLD WAR I

Body armor was initially popular in the American Civil War although neither army developed standards nor issued body armor. Design and testing devolved to private companies that manufactured the armor. Mass production techniques ensured that large numbers of body armor vests could be manufactured at an affordable cost, and they were widely advertised. Several models were made: a lighter version for infantry and a heavier model for cavalry and artillery soldiers. Generally, two or four steel plates were joined together and secured over the shoulder. A higher quality (albeit more expensive) version was manufactured for officers. As the war continued, however, body armor began to fall out of favor. The lack of standards, cumbersome designs, weight, poor fit, inconsistent protection, and cheaply made vests sold by profiteers all diminished enthusiasm for the product. In addition, a stigma of cowardice became attached to those who wore the armor.

The limitations of body armor in protecting all parts of the body is illustrated by the assassination of Archduke Franz Ferdinand of Austria, heir to the throne of Austria-Hungary, whose slaying sparked the First World War. At the time of his shooting, the archduke was wearing a silk bullet-proof vest that had been proven to stop pistol rounds. But the archduke was shot in the neck, and died.[1]

CURRENT US MILITARY BODY ARMOR

Modern US Army body armor has evolved with efforts to optimize the protection of the soldiers from projectiles while increasing the armor's mobility and ease of wear. Other objectives include reducing the armor's weight, engineering constraints, and costs. Today's armor demonstrates a marked improvement over the Personnel Armor System for Ground Troops (PASGT) vest, used from the mid-1980s into the beginning of Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF), the first US body armor made of Kevlar (Dupont; Wilmington, DE), as well as the Vietnam-era fragmentation vest, made of ballistic nylon. Both were designed to offer protection against fragmentation (ie, fragments or other products of explosions) only, although the PASGT could stop pistol rounds. Current body armor uses extremely hard ceramic plate inserts that are made by sintering (fusing under high heat) a variety of nonmetallic minerals. Projectiles will fragment ceramic plates by themselves, so they are generally backed by a fiber-composite compound to contain the ceramic when the armor is struck.[2]

Developing optimal body armor is a work in progress, and is greatly dependent upon reports and feedback from the field. The older outer tactical vest (OTV), a variant of the Interceptor armor (a bullet-resistant vest developed in the late 1990s), was replaced by an enhanced version known as the improved outer tactical vest (IOTV). Insufficiencies of the OTV design led to the development and fielding of the IOTV, which was first fielded to service members in late 2007. One of the improvements of the IOTV over the OTV is a reduction in weight; the medium IOTV weighs 3.6 pounds less than a medium OTV vest. The IOTV can be fitted with multiple components, depending on the mission, threat level, environment, and commander's directives. For example, a mounted soldier serving as a turret gunner could wear all components for maximum

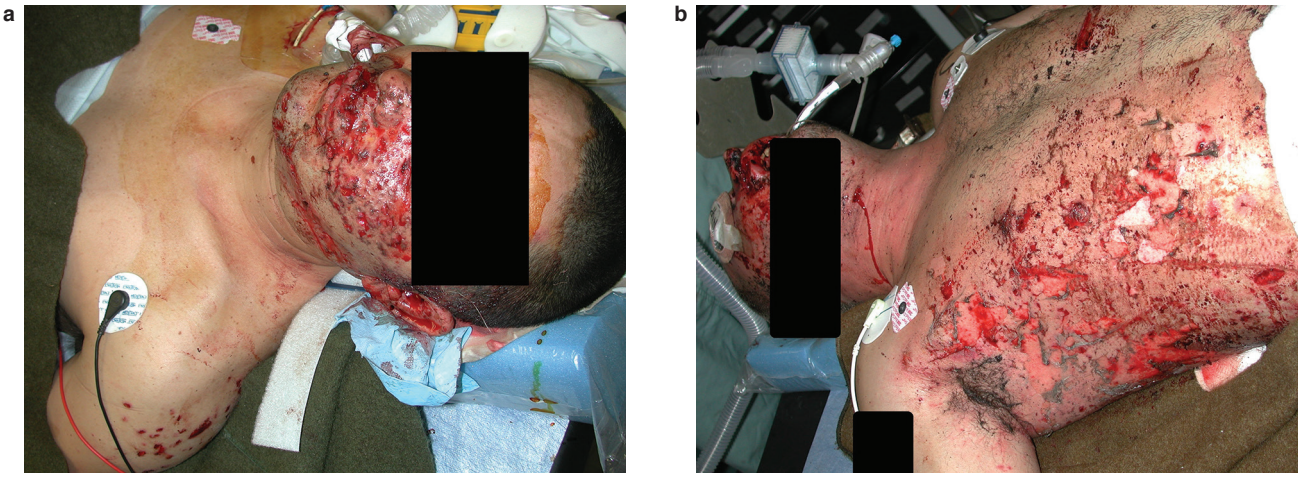

Figure 7-1. (**a**) Improvised explosive device injury in a casualty wearing body armor with protection of torso. (**b**) Improvised explosive device injury in a patient without body armor who sustained torso injuries.

protection, although a dismounted soldier would be more hampered by the armor's weight and movement restrictions. The IOTV's components include a yoke and collar, as well as reversible side carriers and a universal side pouch. Each component adds weight; a fully loaded large IOTV with soft armor panel inserts, ballistic plate inserts, collar, and groin protectors weighs 35 pounds. The Army has developed other variants of body armor, fielding the modular body armor vest and the soldier plate carrier system, both of which provide less armor coverage than the IOTV but are lighter.

One of the IOTV's major design improvements is a quick-release system activated by a lanyard. This feature allows the wearer to quickly escape from the armor, whether submerged or in a burning vehicle. The lanyard can also be activated by a medic to gain better access to a casualty. Another major advance in body armor has been the design and fielding of an IOTV specifically designed for female soldiers. Among other modifications, the vest is shorter to fit shorter torsos, and incorporates smaller side ballistic inserts. These changes improved the female soldiers' mobility and increased comfort while still maintaining protection of the torso.

Despite these improvements, current body armor remains heavy and uncomfortable, and it can impair physical performance and increase thermal stress. It has been demonstrated that wearing body armor impairs repeated high-intensity military task performance.[3,4] These problems are outweighed by provided protection, however.

There is no evidence that modern body armor causes wounds to the head, face, or neck (HFN), either by channeling or by ricochet, but it does reduce lethal injuries to the torso (Figure 7-1).[2] However, body armor does not protect the head, face, neck, or extremities.[5–12] Although the head and neck comprise about 9% of the body's area, 21% of battle-injured patients had at least one wound to the head and neck.[5] An analysis of 4,623 combat explosions in Iraq between March 2004 and December 2007 demonstrated that the extremities were the most frequently injured (41.3%), followed by injuries to the head and neck (37.4%) and torso (8.8%).[13]

Military munitions cause multiple injuries with complex patterns far beyond those seen in civilian injuries. In Afghanistan and Iraq, explosions have caused a greater percentage of injuries than in any previous large-scale conflict.[14] The most common mechanism of injury is the IED, generally at close range. These devices can range from homemade explosives to sophisticated weapon systems containing high-grade explosives. This mechanism of wounding is associated with multiple, high-velocity injuries, widely distributed over the body.[13,15,16]

BODY ARMOR IN LAW ENFORCEMENT

It has been estimated that more than 3,000 US law enforcement officers' lives have been saved over the past 30 years with body armor, and that providing police with body armor is cost effective.[17] Like military personnel, law enforcement officers wear differing types of body armor, depending on their mission.

Thus SWAT teams tend to wear armor capable of stopping armor-piercing rounds, patrol officers wear lighter-weight armor to stop pistol rounds, and correctional officers wear body armor designed to defeat stabbing attempts. The National Institute of Justice (NIJ) has conducted research and established standards to develop ballistic-resistant and stab-resistant armor (Table 7-1). Although military standards do not require body armor to be NIJ-certified, the IOTV can withstand a direct impact from a 7.62 mm rifle round on the front or rear plates (NIJ standard III). The new enhanced small arms protective insert (E-SAPI) plates will provide protection from armor-piercing rounds (NIJ standard IV). Scientists at the Army Research Laboratory at Aberdeen Proving Ground in Maryland have recently reduced the weight of a medium E-SAPI plate from 5.45 to 4.9 pounds. They used a surface treatment technique to hold the ceramic plates together for several microseconds longer, to reduce the bullet's momentum, and an improved plastic backing to reduce trauma to the wearer. If the ballistic ceramic plates are not inserted, the IOTV can protect from 9 mm rounds and fragmentation (standard II or IIA).

TABLE 7-1

NATIONAL INSTITUTE OF JUSTICE BODY ARMOR CLASSIFICATION*

Type	Weapon Protected Against
IIA	9 mm; .40 Smith and Wesson
II	9 mm; .357 Magnum
IIIA	.357 SIG; .44 Magnum
III	rifle, 7.62 mm full metal jacket
IV	armor-piercing rifle, .30 caliber

*Lists examples of the weapon and caliber of ammunition that each type of body armor protects against.

WHY MORE CASUALTIES ARE SURVIVING

The percentage of casualties dying of their wounds in major US conflicts has decreased from war to war (Table 7-2). Rather than attempting to pinpoint one contributing factor to the improved survival rate, it is more productive to view combat trauma survivability as a "system of systems." The US military has developed an integrated medical complex for treating combat casualties that extends in a continuum of care from the point of wounding anywhere in the world to quaternary facilities in the United States (Table 7-3). Components of the improved system include better training of first responders, better equipment, faster transportation, far-forward deployment of more highly qualified practitioners, an integrated joint environment, and a systematic analysis of all aspects of injury.

Each role of care has the same treatment capabilities as earlier roles but adds a new increment of treatment capability. Wounded personnel may bypass a role if their condition and the combat environment permit. For example, a gravely wounded soldier might be evacuated directly from point of wounding to a combat support hospital via medical evacuation (MEDEVAC).

Squad-Level Care

It is essential to recognize that the quality of medical care provided at the lowest levels impacts the outcomes recorded at the higher levels. Thus, self-aid, buddy aid, combat lifesavers (CLSs), and combat medics influence the outcomes of highly trained surgeons. Soldiers receive training in the principles of first aid and buddy aid during their initial military training. All soldiers also attend the Basic Life Support course, taught to the curriculum and standards of the American Heart Association, consisting of 4 hours of both didactic and hands-on training, with retraining required every 2 years. A CLS is a soldier whose primary expertise is in a nonmedical arena but who has been provided with advanced skills and training in the management of combat-related emergencies. The

TABLE 7-2

PERCENTAGE OF COMBATANTS DYING OF WOUNDS BY CONFLICT, AND PERCENTAGE OF WOUNDS TO THE HEAD, FACE, AND NECK

Conflict	Percentage Dying of Wounds	Wounds to the Head, Face, and Neck, Percent
World War II	30	16
Vietnam	24	16
Operation Iraqi Freedom	10	26–36

Data sources: (1) Brennan J. Experience of first deployed otolaryngology team in Operation Iraqi Freedom: the changing face of combat injuries. *Otolaryngol Head Neck Surg*. 2006;134(1):100–105. (2) Brennan J. Head and neck trauma in Iraq and Afghanistan: different war, different surgery, lessons learned. *Laryngoscope*. 2013;123(10):2411–2417.

TABLE 7-3

RESOURCES AVAILABLE THROUGHOUT THE MILITARY HEALTHCARE CONTINUUM

Role	Level or Location	Care Provided	Facilities	Mobility	Providers
1	Unit level	Treatment at point of injury, maintaining airway, controlling hemorrhage, preparing for evacuation	Battalion aid station, shock trauma platoon (USMC)	Mobile	Self-aid, buddy aid, combat lifesaver, combat medics/corpsmen, physician assistant, physician
2	Division level	Forward surgical resuscitation and stabilization, limited patient holding capacity	Medical company forward surgical teams (Army), mobile field surgical team (USAF), forward resuscitative surgical system (USMC)	Mobile	Surgeons, anesthetic care
3	Corps level	Advanced medical, surgical, and trauma care with inpatient capacity, ICUs	Combat support hospitals (Army), theater hospital (USAF), casualty receiving ship (USN)	Mobile	Surgeons, physicians
4	Outside the combat zone	Definitive inpatient medical and surgical care	Overseas, self-sustaining, tertiary-care, general hospital (Landstuhl Regional Medical Center) or USN hospital ship	Fixed	Surgeons, medical specialists
NA	Continental United States	Most definitive care available, full rehabilitative or reconstructive care	Tertiary and quaternary medical centers	Fixed	All specialists

ICU: intensive care unit; NA: not applicable; USAF: US Air Force; USMC: US Marine Corps; USN: US Navy
Data sources: (1) Bagg MR, Covey DC, Powell ET 4th. Levels of medical care in the global war on terrorism. *J Am Acad Orthop Surg*. 2006;14(10 Spec No.):S7–S9. (2) Hospenthal DR, Green AD, Crouch HK, et al. Infection prevention and control in deployed military medical treatment facilities. *J Trauma*. 2011;71(2 Suppl 2):S290–298.

CLS acts as a bridge between self-aid or buddy aid and the combat medic, providing lifesaving measures as the primary combat mission allows, or assisting the medic in providing care. CLS training is focused upon the early management of injuries associated with combat, including airway management, control of extensive bleeding, management of shock, care for chest injuries (include tension pneumothorax), and casualty evacuation techniques. The CLS course generally lasts 40 hours and consists of both didactic and practical training. The goal is to have one CLS per squad, crew, or team.

Better Combat Medic Training

Combat medics (68W) are the second largest military occupational specialty (MOS) in the Army, with about 40,000 soldiers. Only infantry has more personnel. Combat medic training is tough, realistic, scenario-driven, and provides training in the skills necessary to be an effective soldier who can survive on the battlefield while providing state-of-the-art military medical care. Medics receive training in emergency care, tactical combat casualty care, casualty triage, and aircraft and ground evacuation. They learn to integrate tactical and technical skills to ensure survivability of their patients and themselves in today's fluid operational environment. Importantly, 68W is the only MOS that requires soldiers to earn and maintain a national certification. Medics are certified to the level of Emergency Medical Technician-Basic (EMT-B), a US national standard for prehospital providers. Certification tests are administered through the National Registry of Emergency Medical Technicians. There is a continuing education and recertification process to maintain proficiency. Combat medics must annually validate their skills and recertify once every 2 years.

Joint Medical Training

The Medical Education and Training Center at Fort Sam Houston, San Antonio, Texas, is a state-of-the-art healthcare education campus that trains enlisted medical personnel from the Army, Navy, Air Force, and

Coast Guard to provide staffing for the world-wide military healthcare network, with over 50 programs and 21,000 graduates a year. The training program recognizes that there are no rigid protocols in combat casualty care; rather, combat trauma management must be modified to best fit the specific tactical situation the provider encounters. Critical to the success of this effort is the selection, training, and equipping of medics who thoroughly understand the best-practice guidelines of trauma management, but can modify them to suit the tactical environment.

In addition to enlisted medical training, the center is beginning to integrate graduate medical education programs and graduate-level allied health training programs. Thus physicians, nurses, and medics now train as they deploy: jointly. For example, the San Antonio Uniformed Services Health Education Consortium runs 35 accredited graduate medical education programs with over 600 interns, residents, and fellows in both the Army and Air Force. Although the Army focuses on managing battlefield trauma and the Air Force on critical-care air transport, military medical treatment facilities (MTFs) in Iraq and Afghanistan were staffed with personnel integrated from the various services.

Improved Airway Management and Hemorrhage Control

How well are medics performing advanced procedures? A retrospective analysis of cricothyroidotomy performed in the prehospital setting during a 22-month period in Afghanistan (OEF) and Iraq (OIF) examined the success rate of medics in placing a surgical airway.[12] Data abstracted from the Joint Theater Trauma Registry (JTTR) revealed that of 11,492 trauma admissions, 80 patients underwent a prehospital cricothyroidotomy (PC), of which 72 met inclusion criteria. The results showed 66% of the patients who underwent PC died. The most common injuries were caused by explosions, gunshot wounds, and blunt trauma, and 82% of the casualties had injuries to the face, neck, or head. Medics attempting a PC in the field had a 33% failure rate, while physicians and physicians in a prehospital setting had a 15% failure rate.[12] Complications included incorrect anatomical placement, bleeding, air leaks, and right mainstem placement. It is important to note that for many medics, placing a PC in a combat situation is often their first opportunity to place an advanced airway. Furthermore, medics perform these procedures in tactically dynamic situations, whereas the more advanced practitioners perform these airway maneuvers in a more controlled environment. The results demonstrate that medics perform a successful advanced airway maneuver in well over half of the grievously wounded patients who require the procedure. The study's authors suggest that additional efforts be made to define the optimal equipment, techniques, and training required to enable combat medics to become more proficient in placing surgical airways.[12]

Historically, the primary cause of death on the battlefield is exsanguination, and the majority of casualties die in the prehospital environment. Efforts have been made to push damage control resuscitation as far forward as possible. Modern concepts of casualty management include the control of catastrophic hemorrhage at point-of-wounding, a more restrained approach to crystalloid fluid resuscitation (while recognizing the need to maintain the patient's perfusion), utilizing blood products as far forward as possible, and prompt evacuation to a surgical facility.[18]

The management of hemorrhage has improved through the widespread use of tourniquets to control bleeding from the extremities. The light-weight combat application tourniquet has been shown to be particularly effective and is widely issued to military personnel. This tourniquet can be self-applied and uses a windlass with a locking mechanism. Also, improved dressings are being used on wounds, including combat gauze containing an advanced hemostatic agent that improves the temporary external control of traumatic bleeding. Combat gauze is impregnated with an inert, naturally occurring mineral known as kaolin, which activates the patient's coagulation cascade, resulting in rapid clotting. The rolled gauze is flexible and pliable, easily contouring to wounds of various configurations.

Greater Availability of a Variety of Blood Products

The provision of blood and blood products to the combat casualty has been revolutionized over the past decade of war, demonstrating the synergy of clinician feedback and a responsive system. The Armed Services Blood Program is a joint program responsible for the collection, processing, storage, and provision of blood and blood products to MTFs throughout the world. As clinical experience accumulated in the forward surgical management of combat casualties (including damage-control resuscitation initiatives, which are heavily reliant upon blood products), published reports demonstrated an enhanced rate of patient survival when fresh frozen plasma, red blood cells, and platelets were administered. In response to this data, the blood program added several new capabilities to enhance the availability of plasma and platelets, including the emergency collection of apheresis platelets, the avail-

ability and transfusion of deglycerolized red cells, quicker diagnostic donor screening, and the establishment of platelet collection facilities in theater.[19] These steps expanded the suite of blood products, and the trauma surgeon now had a broader armamentarium to treat patients, with casualties treated at forward MTFs benefitted from fresher red blood cell units, fresh frozen plasma, cryoprecipitate, and platelets.

The Lethal Triad

Patients with severe traumatic injuries suffer from hypothermia, acidosis, and coagulopathy, known as the "lethal triad." This condition is associated with a marked rise in mortality. The central tenet of damage control surgery is to rectify the lethal triad, rather than merely correcting the damaged anatomy.[20] Fundamental to the success of this technique is recognizing which patients can benefit from the approach, expeditiously controlling hemorrhage in the operating room, taking aggressive measures to raise the patient's temperature, restoring normal acid-base balance in the intensive care unit, and then proceeding with more definitive repairs in a staged fashion.

Medical Evacuation and Forward Placement of Surgeons

There are a number of other reasons that wounded service members are surviving. The United States has absolute air dominance, allowing almost unfettered air movement through the theater, excluding threats at low altitude from ground-based weapon systems. This dominance allows for rapid clearing of the battlefield through ground-based ambulances and MEDEVAC helicopters.[21,22] Medical facilities with heightened surgical capabilities are positioned throughout the combat zone to provide rapid surgical stabilization. The forward deployment of surgeons, including operators in forward surgical teams, mobile field surgical teams, and shock trauma platoons, allows casualties to undergo lifesaving surgery quickly, generally within the "golden hour" (the critical timeframe within 1 hour after traumatic injury when treatment should occur). The participation of surgical subspecialists offers the opportunity for definitive, lifesaving surgery, often within an hour of wounding.[23]

Airborne Intensive Care Units

Critical care air-transport teams (CCATTs) are flying intensive care units that provide for monitored transfer of critically wounded casualties (with multisystem trauma, extensive burns, or respiratory or multiorgan failure) from OEF and OIF to Role 4 and 5 facilities. The three-member CCATT team consists of a physician with expertise in critical care (eg, emergency medicine, anesthesiology, pulmonary medicine, or surgery), a critical care nurse, and a cardiopulmonary technician. These teams and their equipment can turn any number of airframes into a flying intensive care unit within minutes, including C-130s, HC-130P King aircraft, C-17s, C-141s, and C5s.

Process Improvement

An important component of the increased survivability of the injured combatant is the processes put in place to periodically evaluate established doctrine and to constantly seek improved guidelines and equipment. One such mechanism is the Committee on Tactical Combat Casualty Care, which develops recommendations that are then submitted to the Defense Health Board. If approved, the recommendations are forwarded to the Assistant Secretary of Defense (Health Affairs). See also the discussion of the Joint Trauma Analysis and Prevention of Injury in Combat Program, below.

EVIDENCE-BASED REVIEW

Studies examining the role of body armor and injury patterns of the wearer have been plagued by common confounders such as retrospective data gathering, a mostly descriptive literature, multiple publications of the same patient data set, and compromised data gathering because of chaotic combat conditions, such as lack of detail when describing the circumstances of combat wounding.[24] Also, data on all specialties and all branches of service are included,[24] and variations in measurements across multiservice institutions and inter-rater reliability create bias in the data.[12] Certified professional medical coders are not present in the lower roles of care, making it difficult to track the nuances of those wounded who are not then referred to a Role 4 or 5 facility.[5] This is a particular challenge for head and neck injuries, with varying expertise among combat medics, nurse practitioners, physician assistants, general medical officers, and surgical specialists.

Some of the data inconsistencies involve the definition of a casualty (with multiple definitions across the US military, NATO, and other allies); the difference between a minor injury and a wound; differentiation between "disease," "non-battle injury," and "wounded"; and even the definition of an MTF.[5] Despite these

limitations, a data set of tremendous value has been collected through the dedicated efforts of committed practitioners.

To accurately compare wounds of varying locations and severity, injuries must be quantified in a standardized fashion. The Injury Severity Score (ISS) is an overarching, anatomically-based calculation to quantify the severity of traumatic injury in patients with trauma to multiple sites (polytrauma).[25] There is a linear correlation between ISS and mortality, morbidity, and length of hospitalization. To calculate the ISS, the body is divided into six regions: head or neck, face, chest, abdomen, extremities, and external (lacerations, contusions, abrasions, and burns on the body surface). A 6-point scale (the Abbreviated Injury Scale or AIS) is then applied to each region, with the following points: minor (1); moderate (2); serious (3); severe (4); critical (5); and maximal (6, nonsurvivable). The highest AIS severity code for each of the three most grievously injured ISS body regions is squared and summed. Thus ISS scores range from 1 to 75. Any AIS score of 6 (ie, lethal) automatically generates a score of 75.

Although it is impossible to collect data in a randomized, blinded, and placebo-controlled manner, several studies have been reported that compare wounding patterns in populations with and without body armor. For example, in OIF, 10% of Marines wearing body armor presented with torso injuries, whereas 24% of Iraqi soldiers without body armor presented with torso injuries.[26,27]

It seems clear that body armor has a protective effect from high-velocity gunshot wounds. In a study from the Israel National Center for Trauma and Emergency Medicine Research, researchers retrospectively compared data compiled from 669 terror-related firearm injuries.[28] Injury characteristics and severity, treatment, and outcomes were compared in unprotected patients (433 civilians, 62.2% of the total) versus protected patients (236 soldiers, 37.8% of the total). Compared to the soldiers with body armor, unprotected civilians had higher injury severity (31% vs 16 % with an ISS of 16 or greater), more intensive care (26% vs 20%), and double the inpatient mortality (8.6% vs 3.4%).[28] Unprotected patients with chest injuries suffered a much higher injury severity when compared to protected patients (41% vs 23% with an ISS of 25 or greater), attributed at least in part to an increase in multiple chest wounds. Abdominal wounds in the unprotected versus protected patients showed a similar pattern. The authors concluded that, in victims of high-velocity gunshot wounds wearing body armor, the rates of injury to the head, brain, chest, and abdominal areas are reduced, as well as the severity of injuries to the chest and abdomen, when compared to victims of high-velocity gunshot wounds who were not wearing body armor.[28]

As previously mentioned, a recent review found no evidence that wearing body armor increased the likelihood of sustaining an injury to the head, face, or neck.[2] The specific question addressed was "do military personnel who wear combat body armor (CBA) have a greater incidence of HFN injuries than others not wearing CBA?" Systematic searches sought prospective or retrospective cohort studies, case-controlled studies, and review articles. Neither randomized controlled trials nor case-controlled series were available. A total of 59 articles were identified for initial review, but 40 of these were removed because they did not meet the inclusion criteria or reported duplicate patient populations. Thus, a total of 19 articles were analyzed: 14 retrospective cohort studies, 4 prospective cohort studies, and 1 review article.[2] Most of the articles using OEF and OIF data gave an overall incidence HFN injuries as a percentage of total body injuries ranging from 18% to 25% (the HFN region is 9% of total body area). Of nine articles that reported the main mechanism of injury, seven listed fragments from IEDs, rocket-propelled grenades, or other explosions, and two reported gunshot wounds as the main mechanism of injury. The authors concluded that the increased incidence of HFN injuries is attributable to the increased survivability of the wounded service member, the increased use of fragmentation devices, and the failure of current body armor to protect the head and neck.[2] A large study from Landstuhl (the Role 4 facility that received most casualties from Afghanistan and Iraq) noted that Kevlar helmets and body armor are effective in preventing intracranial and torso wounds, and that the majority of combat wounds were secondary to fragmentation and shrapnel rather than bullets.[5] Fragmentation injuries differ from gunshot wounds, with a greater distribution, multiple entry points, and multiple organ involvement (Figure 7-2).[2]

The JTTR was established to capture the demographics and trauma-related data on all US service members injured while deployed to OEF and OIF. This electronic war injury registry provides medical data analyzed from the initial evaluation and stabilization of the wounded service member through transport across the combat theater to the most sophisticated military hospital in the United States. The JTTR was established in 2003, approximately 16 months after OEF began. Thus, while it is the most comprehensive database available, it does not completely capture all of the injuries of the war years. The Institute for Surgical Research at Fort Sam Houston is the repository for the JTTR.

Figure 7-2. Mosul dining hall human-borne improvised explosive device site in December 2004.

Analysis of the JTTR clearly shows that the primary cause of significant wounding of US service members was explosions (78%); the proportion of gunshot wounds was 18%.[14] The database was queried for all service members receiving treatment for wounds sustained in Iraqi and Afghanistan from October 2001 through January 2005. A total of 3,102 casualties were identified, of which 31% were classified as non-battle injuries, and 18% were returned to duty within 72 hours. These injuries were excluded from further analysis, leaving 1,566 combatants with 6,609 combat wounds. Of these wounds, the locations were: extremity (54%), abdomen (11%), face (10%), head (8%), thorax (6%), eyes (6%), ears (< 3%), and neck (< 3%).[14] While historical head and neck proportions ranged from 16% to 21% (World War II, Korea, and Vietnam), the proportion of head and neck wounds in the current conflicts (30%) is significantly higher ($p < 0.0001$). Concurrently, thoracic wounds decreased 13% from World War II and Vietnam ($p < 0.0001$).[14]

To focus on the number and type of facial and penetrating neck injuries, the JTTR was queried for both OIF and OEF from January 2003 to May 2011. These data were the basis for the Joint Facial and Invasive Neck Trauma (J-FAINT) project, which analyzed information on demographics and type and severity of facial, neck, and associated trauma.[29] The impact of these injuries on overall mortality was recorded. The J-FAINT study identified 7,177 service members with a total of 37,523 discrete facial and penetrating neck injuries.[29] Of these injuries, 25,834 were soft tissue injuries and 11,689 were facial fractures. Most injuries were described as mild to moderate, with the most common soft injury sites being the face and cheek (48%), the neck/larynx/trachea (17%), and the mouth and lip (12%). Among the 11,689 facial fractures, the maxilla (24.46%), mandible (20.85%), orbit (19.17%), teeth (13.35%), and nose (12.27%) accounted for the majority of fracture sites.[14] The injuries were associated with an overall mortality rate of 3.5%.[29]

Not surprisingly, the vast majority of injured personnel were male (97.5%), in the Army (75%), and in OIF (73.3%).[29] The average wounded service member sustained more than five separate facial and penetrating neck injuries, with 31% including facial fractures and 5% with damage to vessels. Mechanisms of injury included penetrating (49.1%), blunt (25.7%), blast (24.2%), and other/unknown/burn (1%).[29] The highest risks for mortality were treatment at a Role 2 facility without forward surgical team capability, female sex, prehospital intubation, and blast injury.[29]

The J-FAINT project results are among the most complete of any data set on OEF and OIF injuries, providing important clues about the proper mixture of medical personnel that should be deployed to manage these conditions as well as the required predeployment training. The results of the study suggest the limitations of body armor, as well as improvements that should be made.[29]

A retrospective review using one head and neck surgeon's operative log book and patient medical records clearly demonstrated that the head and neck trauma experience in Iraq (142 patients from 13 September 2004 to 13 January 2005,) was markedly different from Afghanistan (156 patients from 20 May to 15 November 2009).[30] The surgeon was assigned to an Air Force theater hospital (Role 3) in both countries. In Iraq, only 10% of patients were pretreated (stabilized by a surgeon before being treated by the head and neck surgeon) at a facility with surgical capabilities, whereas in Afghanistan, 93% of patients were pretreated. Thus control of bleeding, emergent airway surgery, and emergent neck exploration were more common in Iraq. Not unexpectedly, mortality for the Iraq patients was 5.3%, and mortality for the patients in Afghanistan was 1.3%. Differences in pretreatment rates appeared to be related to the Role 3 hospital being geographically close to the point of wounding in Iraq, with air evacuation times approximating 40 minutes. In contrast, the Role 3 facility was 2 to 3 hours by air from the point of wounding in Afghanistan, with care generally being provided at intervening Role 2 and 3 facilities before the patient was by the head and neck surgeon. As a consequence, facial fracture repairs comprised 16.5% of the Afghanistan caseload, and only 3% of the surgical volume in Iraq.[30]

In recognition of the need for forward deployed head and neck experts, an Air Force otolaryngology team was deployed to Iraq in 2004.[23] In the initial 2-month period of the deployment (October and November 2004), 170 patients were operated on with the

intent to save life or eyesight. The otolaryngologist was the primary surgeon on 63 patients (37%), followed by an ophthalmologist for 44 patients (26%), a neurosurgeon for 37 (22%), and an oral surgeon for 26 (15%).[23] Twenty-seven patients underwent exploration for penetrating trauma, with a mortality of 4%. Injuries were to zone I in six cases, zone II in 20 cases, and zone III in 1 case. Major intraoperative pathology was noted in 78% of the cases explored.[23] Because relatively innocuous wounds can cause major internal neck injuries, a high index of suspicion must be maintained in managing high-velocity penetrating neck trauma. All symptomatic patients must be explored. All asymptomatic patients were examined with plain anteroposterior and lateral films. If fragments were demonstrated medial to the sternocleidomastoid muscle, computerized tomographic angiography was used to examine the carotid sheath, and pandendoscopy was performed if indicated.

The otolaryngology team also had an active outpatient practice. Of the 529 outpatient visits, the most common diagnoses were hearing loss after acoustic trauma (59 cases), superficial wounds with one-layer closure (requiring only one skin layer to be closed, as opposed to deeper wounds needing several layers of closure) or observation (53 cases), tympanic membrane perforation (47 cases), chronic otitis media (46 cases), and otitis externa (30 cases).[23] It was noted that, while non-otolaryngology practitioners felt that tympanic membrane perforation was a disabling injury, the otolaryngology team noted that most patients with a tympanic membrane perforation were fit for duty after relatively straightforward management.[23]

Another study examined 63 patients with combat-related penetrating cervical trauma after their transfer to a Role 4 facility.[31] Injuries were to zone II in 33% of cases, zone III in 33%, and zone I in 11%, with the

EXHIBIT 7-1

HEAD AND NECK LESSONS LEARNED FROM THE CONFLICTS IN IRAQ AND AFGHANISTAN

- The use of body armor has resulted in new patterns of wounding.
- In the current wars, head and neck injuries account for 16% to 21% of all battle injuries.
- Soft tissue can be closed immediately after extensive irrigation and conservative debridement, removing grossly devitalized tissue only.
- Passive Penrose drains may have a lower infection rate than closed-suction Jackson-Pratt drains.
- In a mass casualty situation, the role of the ENT surgeon is airway and hemorrhage control.
- The immediate goals of soft tissue reconstruction are to reapproximate the wound edges with primary closure (avoiding extensive undermining and flap rotation), and to achieve soft tissue coverage of exposed bone and plates.
- Soldiers can still function with ruptured tympanic membranes.
- In a combat setting, the three most common procedures are (1) repair of complex facial lacerations, (2) tracheostomy, and (3) neck exploration.
- Once a neck injury patient has been evacuated, maintain a high index of suspicion for occult injury with a low threshold for arteriography.
- Craniofacial plates rarely get infected, with only 2/115 (1.7%) plates placed in Afghanistan requiring removal; no mandibular plates required removal.
- Consider neck exploration in all patients, even if symptomatic.
- The three most important goals of mandibular fracture repair are occlusion, occlusion, occlusion!
- High-velocity Le Fort III fractures requiring panfacial repairs are best managed by initially setting the base with IMF or ORIF of the mandible, then exposing the midface fracture sites and building the midface from stable to unstable points, while ensuring that the midface height and projection are preserved.

Quotations reproduced from: United Kingdom Ministry of Defence. *The Joint Service Manual of the Law of Armed Conflict*. Shrivenham, UK: Ministry of Defence; 2004. Joint Service Publication 383.

ENT: ear, nose, and throat; IMF: intermaxillary fixation; ORIF: open reduction and internal fixation

Data sources: (1) Xydakis MS, Fravell MD, Nasser KE, Casler JD. Analysis of battlefield head and neck injuries in Iraq and Afghanistan. *Otolaryngol Head Neck Surg*. 2005;133(4):497–504. (2) Brennan J. Experience of first deployed otolaryngology team in Operation Iraqi Freedom: the changing face of combat injuries. *Otolaryngol Head Neck Surg*. 2006;134(1):100–105. (3) Brennan J. Head and neck trauma in Iraq and Afghanistan: different war, different surgery, lessons learned. *Laryngoscope*. 2013;123(10):2411–2417. (4) Fox CJ, Gillespie DL, Weber MA, et al. Delayed evaluation of combat-related penetrating neck trauma. *J Vasc Surg*. 2006;44(1):86–93.

remainder involving injuries to multiple zones. The method of wounding was explosions in 79% of cases and gunshot wounds in 21%. Of the 63 patients, 39 (62%) had undergone emergent neck exploration prior to evacuation, and 21 patients required emergent repair.[31] After evacuation, all patients underwent radiological evaluation, using a combination of plain films and computerized tomographic angiography. Because computed tomography angiography was subject to degradation from retained fragments, 40 patients (63%) underwent diagnostic arteriography, which detected 13 additional occult injuries and 1 graft thrombosis in 11 patients.[31] The authors emphasized the need for a complete reevaluation upon evacuation to the continental United States (Role 4) in patients with cervical injuries.[31] Exhibit 7-1 lists lessons learned from managing head and neck injuries in OEF and OIF.

INFECTIOUS DISEASES ASSOCIATED WITH HEAD AND NECK INJURIES

The improved survivability of patients is associated with its own set of consequences, including healthcare-associated infections, particularly with multidrug-resistant pathogens. In the past, combat–related infections occurred early after wounding, and were generally secondary to pathogens that contaminated wounds at the point of wounding. Thus, *Clostridium perfringes* (soil), *Streptococcus pyogenes* (skin), *Staphylococcus aureus* (skin), and gastrointestinal flora could contaminate wounds. With the advent of swift surgical management, including debridement of devitalized tissue, removal of foreign bodies and clots, irrigation, and elimination of fluid collection and dead space, along with topical and systemic antimicrobials, infections with these organisms acquired from the wounding environment or the casualty's own flora have been reduced. They have been replaced by infections with multidrug-resistant organisms transmitted from the hands of healthcare workers, other patients, or the hospital environment. Thus, war wounds are now being colonized and infected with multidrug-resistant gram-negative bacilli, including *Acinetobacter baumannii-calcoaceticus* complex, extended-spectrum β-lactamase-producing Enterobacteriaceae (*Escherichia coli, Klebsiella pneumoniae*, *Pseudomonas aeruginosa)*, and methicillin-resistant *S aureus*.[32] Studies demonstrate that US military personnel are not colonized with these organisms prior to wounding, with the possible exception of methicillin-resistant *S aureus*.[33,34]

Providing care to host nation and other non-US patients is ethically mandated and consonant with US roles of entitlement, but these patients can be a source of multidrug-resistant organisms that can lead to infections in US personnel.[32] Other challenges to controlling these infections include high personnel turnover rates, the physical structure of MTFs (eg, tent hospitals are more porous), environmental conditions, and a complex logistics chain that can result in a temporary shortage of hygienic supplies. These concerns can be mitigated by a command emphasis on infection control, from such staples as hand hygiene and isolation to cohorting and antibiotic control measures. Such a command emphasis in MTFs throughout the evacuation chain is essential to reducing healthcare-associated infections.

FUTURE DIRECTIONS

The Joint Trauma Analysis and Prevention of Injury in Combat Program

To mitigate the inordinately complex sequence of events of combat trauma in the future, it is imperative to take a formalized, critical look at the current situation. One challenge is that many disparate military communities look at improving survivability from their own perspective, often without full knowledge of the operational context within which the injuries or fatalities were sustained. The medical community focuses on battlefield medicine, and no formal process has been available for providing meaningful medical injury data associated with combat operations to nonmedical users such as combatant commanders, materiel developers, and requirement developers. Protective equipment developers have focused on performance specifications, intelligence analyses were not shared with the medical personnel or researchers, and no operational context existed to provide an in-depth understanding of how soldiers were being injured and killed on the battlefield.

In an effort to improve joint information sharing and collaboration for the analysis and ultimate prevention of traumatic injuries in combat, the Joint Trauma Analysis and Prevention of Injury in Combat (JTAPIC) Program was established at the Medical Research and Materiel Command, at Fort Detrick, Maryland, in July 2006. A collaboration among various Army, Navy, and Marine Corps units, JTAPIC's mission is to collect, integrate, analyze, and store operational information,

intelligence, materiel performance, and medical data to inform efforts to prevent or mitigate injury during the full range of military operations. JTAPIC partners (Exhibit 7-2) possess deep expertise across all aspects of combat trauma. The JTAPIC Program has provided actionable information to senior decision-makers and responsible proponents, including data leading to body armor improvements that have enhanced soldier survivability.

Improving Hemorrhage Control

Uncontrollable hemorrhage remains the primary cause of battlefield deaths. It is therefore of major interest to determine how to staunch life-threatening hemorrhage in what are currently classified as non-compressible injuries. Research continues on devices to prevent exsanguination through the control of junctional area (pelvis, groin, and axilla) hemorrhage. One such device is the abdominal aortic tourniquet, designed to be used in the prehospital setting to prevent pelvic and proximal lower limb hemorrhage by means of external aortic compression.[35] In one experiment, the abdominal aortic tourniquet was applied while blood flow was monitored in the common femoral artery by Doppler ultrasound; blood flow was eliminated in 15 of 16 healthy volunteers. Another strategy is to design optimal fluid strategies for resuscitation. One such effort is ongoing research on damage control resuscitation, which limits the amount of crystalloid or colloids infused and instead uses plasma and other blood products for the treatment of severe hemorrhage.[36]

EXHIBIT 7-2

PARTNERS IN THE JOINT TRAUMA ANALYSIS AND PREVENTION OF INJURY IN COMBAT PROGRAM

- Army National Ground Intelligence Center
- Armed Forces Medical Examiner
- Program Management for Soldier Protection and Individual Equipment
- Army Research Laboratory
- Army Aeromedical Research Laboratory
- Army Institute of Surgical Research
- Army Infantry Center
- Natick Soldier Research, Development, and Engineering Center
- Naval Health Research Center
- Marine Corps Systems Command

Adapting Existing Technologies to Wartime Injuries

One example of adapting current medical technology to combat injuries is ablative fractionated laser technology. Originally developed for cosmetic surgery, fractionated laser technology demonstrates the potential for resurfacing traumatic scars and contractures.[37] This technique can effectively improve the texture and flexibility of scar tissue, softening the scar, increasing pliability, and concomitantly increasing range of motion. Advances in fields such as diagnosis and treatment of brain injury, regenerative medicine, and rehabilitation are also being made.

Improved Ballistic Protection of the Face and Eyes

Although antiballistic eyewear is available, no such lightweight protection is currently available for the face.[2] Full-face visors have been proposed, but current material limitations prevent protection against high-velocity projectiles. Available neck protectors are not satisfactory and have limited compliance because of design and mobility constraints; thus there is interest in developing neck protection that is comfortable and does not limit movement.[6,7] However, significant challenges remain because the neck is fundamentally different from the thorax in terms of anatomical vulnerability, flexibility, and equipment integration.[9] Also needed is improved eye protection that does not inhibit vision. Soldiers are reluctant to wear currently available eye protection because of reduced visibility, although it seems clear that current levels of eye injury could be reduced with improved compliance.[7,8]

In response to facial injuries from IEDs suffered in Iraq and Afghanistan, the Natick Soldier Research, Development, and Engineering Center in Massachusetts has developed modular helmet designs that incorporate removable face shields and mandibular protection. The new designs incorporate advances in protective materials, as well as heads-up display and communications technologies, but are several years away from being fielded.

The "Iron Man" Suit

There is a great deal of interest in developing an "exoskeleton" for the soldier that would provide full-body ballistic protection without the limitations of current-day body armor, that would also increase mobility, surveillance abilities, and physiological performance. An integrated family of systems would provide the capacity to carry heavy loads and significantly improve endurance and mobility while controlling the wearer's thermal environment, integrate

power sources, monitor vital functions and assess physiological reserve, staunch hemorrhage, enhance situational awareness through integrated sensors, and increase cognitive performance. Sensors would report the wearer's location, and many of the devices would be powered by converting the wearer's stride to electricity. The Special Operations Command is seeking such a "smart" combat suit, called the Tactical Assault Light Operator Suit (TALOS), or the "Iron Man" suit. Obviously, formidable obstacles must be overcome before TALOS is fielded, including the issue of power. The name "TALOS" was chosen in recognition of the need to overcome critical vulnerabilities: in Greek mythology, Talos was a giant whose only weakness was having a single vein that ran from head to ankle; once this vein was opened, Talos perished.

Novel Materials

A substance with the potential to revolutionize body armor is a two-dimensional material known as graphene, which is composed of a single layer of carbon atoms bonded together in a repeating pattern of hexagons, resembling a honeycomb lattice (or chicken wire) structure. A million times thinner than paper, it is one of the strongest materials known. Graphene weighs very little (0.77 g/m^2), but is 100 times stronger than steel of the same thickness. A sheet of graphene is calculated to have the capacity to support an elephant balancing on a pencil. Graphene is transparent, bendable, stretchable, and a superb conductor of heat and electricity. The raw material of graphene is graphite, which is a plentiful material most familiar as pencil lead. In fact, a pencil lead is composed of many millions of layers of graphene.

While it is not likely that body armor could be made of pure graphene, the possibility exists of incorporating graphene sheets into a composite material.[38] Such graphene-polymer composites, perhaps incorporating carbon nanotubes (made of rolled graphene), have the potential to be an exceptionally strong and light material for body armor, although issues such as ease of manufacturing and cost will need to be resolved.

Another potential approach to making body armor stronger, lighter, and more flexible is using materials incorporating magnetorheological fluids, which can change from a liquid state to a solid in milliseconds when a magnetic field or electrical current is applied. Body armor made of magnetorheological materials would be soft and pliable but could harden almost instantaneously when impacted.

The Defense Health Agency

Innovations are not restricted to technology such as TALOS suits and graphene. In the largest reorganization of the military health system since World War II, the Defense Health Agency (DHA) was created to manage the activities of the Military Health System, composed of the healthcare organizations of the Army, Navy (which is responsible for the Marine Corps), and Air Force. The DHA is now responsible for many of the common health services that support operational forces, such as providing support for military medical commands, overseeing the Tricare program, and integrating information technology, facilities planning, education, and research. The DHA is designed to eliminate duplication and to combine and streamline operations, integrating a variety of health and delivery systems to best accomplish the Department of Defense's "quadruple aim": to achieve medical readiness, improve the health of personnel, enhance the experience of care, and lower costs.

SUMMARY

Current weapons employed against military personnel result in a high incidence of HFN trauma because existing body armor does not protect these areas of the body. Although the development of better systems is continuing, extant biomaterial and engineering strategies cannot offer full protection to the soldier, while allowing full functionality in a tactical environment, for the foreseeable future. These facts mandate that surgical subspecialists with expertise in managing these potentially devastating injuries be deployed as close as is feasible to the point of wounding.

Military medicine has been transformed by the wars in Iraq and Afghanistan, with survivability of wounded service members at a historic high. Military medical advances made on the battlefield readily translate to civilian medicine, as witnessed by the superb response to the 2013 Boston Marathon bombings. But there is a concern that, with budget cuts, sequestration, and other fiscal issues, investments in trauma research and care will dwindle. Although interest and resources committed to trauma care historically peak during wartime and wane during peacetime, the attacks on September 11, 2001, and subsequent events clearly demonstrate that no forthcoming armistice will end the threat of violence, either in the United States and abroad. Every effort must be made for the military to stay connected with the civilian clinical and research communities, to share best practices and advances, and to collaborate to improve trauma care, not just for service members, but for all Americans.

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