Improved Characterization of Combat Injury

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Background: Combat injury patterns differ from civilian trauma in that the former are largely explosion-related, comprising multiple mechanistic and fragment injuries and high-kinetic-energy bullets. Further, unlike civilians, U.S. armed forces combatants are usually heavily protected with helmets and Kevlar body armor with ceramic plate inserts. Searchable databases providing actionable, statistically valid knowledge of body surface entry wounds and resulting organ injury severity are essential to understanding combat trauma.

Methods: Two tools were developed to address these unique aspects of combat injury: (1) the Surface Wound Mapping (SWM) database and Surface Wound Analysis Tool (SWAT) software that were developed to generate 3D density maps of point-of-surface wound entry and resultant anatomic injury severity; and (2) the Abbreviated Injury Scale (AIS) 2005-Military that was developed by a panel of military trauma surgeons to account for multiple injury etiology from explosions and other high-kinetic-energy weapons. Combined data from the Joint Theater Trauma Registry, Navy/Marine Combat Trauma Registry, and the Armed Forces Medical Examiner System Mortality Trauma Registry were coded in AIS 2005-Military, entered into the SWM database, and analyzed for entrance site and wounding path.

Results: When data on 1,151 patients, who had a total of 3,500 surface wounds and 12,889 injuries, were entered into SWM, surface wounds averaged 3.0 per casualty and injuries averaged 11.2 per casualty. Of the 3,500 surface wounds, 2,496 (71%) were entrance wounds with 6,631 (51%) associated internal injuries, with 2.2 entrance wounds and 5.8 associated injuries per casualty (some details cannot be given because of operational security). Crude deaths rates were calculated using Maximum AIS-Military.

Conclusion: These new tools have been successfully implemented to describe combat injury, mortality, and distribution of wounds and associated injuries. AIS 2005-Military is a more precise assignment of severity to military injuries. SWM has brought data from all three combat registries together into one analyzable database. SWM and SWAT allow visualization of wounds and associated injuries by region on a 3D model of the body.

Key Words: Abbreviated Injury Scale (AIS), Maximum AIS (MAIS), AIS 2005-Military, Maximum AIS Military (MAIS-Military), Combat registry, Combat injury, Combat casualty, Injury, Database, Wounds.

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There are several substantial differences between civilian and combat trauma and their corresponding trauma systems. Similar to their civilian counterparts, however, military trauma systems need trauma registries that adequately describe injuries to control for case mix differences (specific to the various phases of combat), to track outcomes over time, and to facilitate quality assessment and improvement. This article describes the development of new tools that have been applied to increase precision of combat injury characterization in the setting of the contemporary U.S. military trauma system. A number of activities were undertaken to better define contemporary combat injury to aid in improving protection, treatment, resourcing, training, and research.

Combat Injury

Most (~70–80%) injuries in deployed military forces occur as a result of hostile action. Approximately half of wounded combatants have minor injuries and return to duty (RTD) within 2 to 3 days. Of the 33,750 U.S. forces wounded in action in Operations Iraqi Freedom (OIF) and Enduring Freedom (OEF) as of February 18, 2009, 18,326 (54%) were RTD within 3 days.[1] Those who receive the full force of the highly lethal weaponry used in modern-day combat, however, suffer a variety of injuries not encountered in civilian practice. Fully three fourths of these injuries are caused by explosive devices,[2] which are designed to cause massive bodily destruction by propelling large numbers of fragments toward the intended victims. Use of explosive devices, particularly roadside improvised explosive devices (IEDs), initiates complex, multi-mechanistic forces on the body from the explosion itself and also by vehicle translocation causing rollover, elevation, and upending or colliding with other

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objects, resulting in occupant blunt trauma. The remaining 20% to 30% of hostile injuries are caused by bullets from small arms. These tend to be of far higher kinetic energy (e.g., AK47s) than those encountered in civilian trauma practice.

The approximately 20% to 30% of non–combat-related injuries in the deployed forces are known as non-battle injuries and include vehicle crashes, falls, and sports injuries. However, many of these also differ from civilian trauma. Military personnel are equipped with personal protective equipment (PPE), such as helmets, goggles, and body armor consisting of a Kevlar jacket. These alter the way in which energy is coupled to the body. PPE substantially protects certain areas of the body from fragment injury. Vehicles may be heavily protected (e.g., the A1M1 tank or mine resistant ambush protected vehicle [MRAP]), or relatively unarmored (e.g., the originally deployed high mobility multipurpose wheeled vehicle [HMMWV] 1114, later uparmored to the 1151).

As much as the epidemiology, nature, and severity of combat wounds are different from civilian trauma, so also are the demographics of combatants (i.e. younger, fitter, overwhelmingly male) and the military system of trauma care.

Joint Theater Trauma System

The Global War on Terror in Afghanistan and Iraq has allowed development/refinement of perhaps the most formidable system of trauma care ever developed: the Joint Theater Trauma System ([JTTS] described previously by Eastridge et al.[3]). Through the JTTS, wounded soldiers are evacuated from the combat zone to Landstuhl Regional Medical Center (Level 4) in Germany usually within 72 hours of injury, and then to one of the Level 5 centers in the continental United States, which include Walter Reed Army Medical Center (Washington, DC), National Naval Medical Center (Bethesda, MD), and Brooke Army Medical Center (San Antonio, TX). The five levels of care in the US military health system are given in Table 1.

TABLE 1. US Military Health System Levels of Care

Level	Description
1	Battalion aid station: immediate basic medical care by medics at the point of wounding
2	Forward surgical teams: surgeon-staffed mobile medical facilities providing initial resuscitation and damage control surgery
3	Combat support hospital: fully equipped field hospital providing resuscitation, damage control surgery and stabilization before evacuation from the combat zone
4	Definitive care out of the combat theater en route to the United States
5	Definitive care in the continental United States

The sophistication of the JTTS, the dedication of the teams involved (from point of wounding to US definitive care facilities), and the innovations that have resulted from the experience gained treating this large number of severely injured patients have improved patient outcomes.[3,4] In the current conflicts, case fatality rates are substantially lower than those experienced in previous conflicts (i.e., the case fatality rate for World War II was 19.1, for Vietnam was 15.8, and for Iraq and Afghanistan, combined, was 9.4).[5] These case fatality rates, which exclude the RTD patient population, are thus not quite comparable to case fatality rates in the civilian sector and probably relatively overstate the military mortalities.[6]

Combat Trauma Registries

Analyzable searchable databases on combat injuries are essential prerequisites to understanding wounding agents and the nature and severity of injuries, and to developing strategies for mitigation (including body/vehicle armor), and treatment. Although individual surgical unit experiences in the literature abound, larger representative samples of clinical data have been hard to come by for combat trauma. War analyses have been generally superficial, often merely counting the number of wounded or dead. Examples of quality analyses include the After Action Reports of the second Auxiliary Surgery (1942–1944), which performed more than 22,000 surgeries during the US military advance through Italy in World War II,[7] and the Wound Data and Munitions Effectiveness Team (WDMET) database, a sample of Vietnam War casualties obtained in 1965–1967 for the purpose of assessing weapons effectiveness. The WDMET database contains data on 7,989 patients (approximately 4% of those wounded and killed in Vietnam). Despite many deficiencies, WDMET data analyses performed by Bellamy et al. have driven military medical doctrine for more than 40 years.[8,9]

Attempts to rectify the lack of combat trauma databases began in the late 1990s with a re-coding of WDMET and an effort to aggregate data from a number of "small" conflicts (Somalia, Panama, Grenada, Northern Ireland, the Falklands) in the 1980s and 1990s. The database included not only injury descriptions and outcome based on Major Trauma Outcome Study[10] formats but also information on weapons, weather, and tactics. When field-tested in Afghanistan in 2002 and later in Iraq, this dataset format proved too unwieldy to work within the combat zone. Subsequent revisions yielded the Joint Theater Trauma Registry (JTTR), control of which was transferred to the US Army Institute of Surgical Research in 2005.

The Navy and Marine Corps moved quickly to benefit from the experiences of field testing in Afghanistan and established the U.S. Navy-Marine Corps Combat Trauma Registry (CTR) at the Naval Health Research Center (NHRC) in San Diego, CA. Further, the Marines developed a process that integrated data collection with patient records and instituted predeployment data collection training. The Marine Commandant issued Fragmentary Orders (FRAGOs) to ensure that all clinical data on combat casualties would be sent to the NHRC. The Navy-Marine database now contains some 85,000 Level 2 patient visits to forward surgical facilities, 28,000 of which have been entered into the CTR. This is the most complete and comprehensive set of data on deployed health visits causing force decrement ever collected. In addition, the Armed Forces Medical Examiner System (AFMES) Mortality Trauma Registry (MTR) was established for the purpose of databasing the decedent injuries.

Software Tools

As OIF and OEF progressed, a major deficiency in the goal of obtaining comprehensive trauma data became evident. Because almost all combat injuries are penetrating, a searchable and analyzable mapping system was required to assess the points of entry and consequent injuries. Two tools, the Surface Wound Mapping (SWM) and Surface Wound Analysis Tool (SWAT), provide this capability. By using this software, data from JTTR, CTR, and MTR are merged into one searchable database.

SWM and SWAT development over a period of 4 years were largely funded by the Defense Advanced Research Projects Agency and the counterterrorist Technical Support Working Group. By using these tools, graphical and statistical patterns of wounding and internal injury on selected populations of combat casualties are displayed. The software suite is being used by all three US military trauma registries to wound-map casualty data for military use. Refinement and expansion of its military use is underway, with the addition of extracts from tactical data sets and the ability to mark up PPE to show damage incurred in combat. This will facilitate development of mission-specific PPE and assist in ongoing decision-making regarding tradeoffs between weight and mobility.

Characterization of combat injury in SWM and SWAT is made possible with advances in injury severity scoring, specifically development of an injury severity scale (based on the Abbreviated Injury Scale [AIS]) that more specifically and precisely describes injuries sustained on the battlefield. The AIS is an anatomically based, consensus-derived, global severity scoring system that classifies each injury by body region according to its relative importance on a six-point ascending scale of severity. It was developed by a panel of experts with many years of experience in different areas of injury expertise and was the first injury severity scale to be adopted and widely used in clinical practice.[11–13] Today, in its sixth, considerably expanded and updated iteration, the AIS (AIS 2005) is the most ubiquitous anatomic injury severity scale in use today [14–17] Despite its considerable expansion through the years (from 73 injury descriptions to 1,996), the AIS was unable to characterize combat injuries, especially those caused by explosions.[18] Thus, the AIS 2005-Military was developed for use in coding contemporary combat injuries.

METHODS

Development of the AIS 2005-Military

AIS 2005 was provided to the project for adaptation for military use and validation on combat-injured patients. The work was performed by a committee of military physicians representing all three services and a spectrum of medical specialties relevant to combat casualty care (emergency medicine; trauma; and orthopedic, neuro- and general surgery) in conjunction with members of the Association of Advancement of Automotive Medicine's (AAAM's) International Injury Scaling Committee (IISC).

Development of the AIS 2005-Military coincided with the revision efforts that would culminate in publication of the general (non-military) AIS 2005, which included additional expanded descriptors for orthopedic trauma based on the Orthopaedic Trauma Association scale and expanded bilateral injury codes, particularly for vessel injuries. The same consensus model used in determining changes to each injury description by the IISC was used to determine AIS 2005-Military scores. The AIS 2005-Military codes were derived by identifying each combat injury that is more severe than the corresponding civilian injury, and increasing the AIS code by one increment of severity. A few injury descriptions were increased by two AIS severity increments to reflect the increased risk of death or morbidity in a military setting. AIS 2005-Military 6 injuries are those which were determined by the panel to be untreatable in-theater, i.e., in the war zone. Despite being untreatable in the combat setting, some casualties will survive transport out of theater to Landstuhl Regional Medical Center in Germany (Level 4) where definitive or supportive treatment is provided.

Neurosurgeons reviewed and revised the head/face, neck, and spine regions (AIS body regions 1, 2, 3, and 6); thoracic surgeons reviewed the thorax (AIS body region 4); general surgeons reviewed the abdomen and pelvis (AIS body region 5); and orthopedic surgeons reviewed the extremities (AIS body regions 7 and 8). Corresponding external injuries were included in the review for each body region and military emergency physicians and trauma surgeons were included as part of each review group. The military emergency physicians and trauma surgeons also reviewed the external/burns/other trauma section (AIS body regions 9 and 0).

Two of the 10 body regions had combat-specific injuries that warranted individual attention. In the thoracic region (AIS body region 4), blast overpressure injury to the lung was discussed in detail. Although the non-military versions of the AIS contain codes for unilateral or bilateral pulmonary contusion, a blast injury to the lung usually involves all lobes, is peripheral, and involves a higher risk of air embolus. After much debate, it was decided that the best approach would be to include the category of "Blast injury (overpressure/explosive) not further specified (AIS 3)" in the lung section, with descriptors of mild (AIS 3), moderate (unilateral/bilateral with pulmonary peripheral hemorrhage, AIS 4) in both AIS 2005 and AIS 2005-Military, and severe (bilateral with air embolus, AIS 5) in AIS 2005 and AIS 6 in AIS 2005-Military.

In the "Other Trauma" section, the category of "Whole Body Explosion Injury" was added, to be used specifically for explosive injuries, with the following descriptors:

- Minor or superficial to skin, subcutaneous tissue and muscle with or without minor fracture(s)—AIS 2;
- Major or extensive (>25% total body surface area) to skin, subcutaneous tissue, and muscle with multiple fractures and/or multiple organ injuries—AIS 4; and
- Massive; multiple organ injury to thorax and/or abdomen with loss of one or more limbs and/or decapitation—AIS 6.

During the review process, the contribution of time to definitive care to injury severity and patient outcome was explored. AIS scores were assigned based on each injury being coded as a separate entity and with the assumption that the patient received definitive care within a reasonable time frame. If the time to care was set aside, then the injury itself was deemed most likely to account for the differences in outcome.

These efforts resulted in completion of AIS 2005-Military, which provides a more precise descriptor of military (especially penetrating) injuries and injuries from explosions, and is beginning to serve as a building block for more precise outcome assessments of military injuries. It also provided the opportunity to establish the relationship with AIS 2005-Military and outcome after slight coding refinements.

Data Acquisition

For the purposes of the current project, combined data (N = 1,151) from the JTTR, CTR, and MTR were coded in AIS 2005-Military and entered into the SWM database. The data include patient demographics, cause and mechanism of injury, wound descriptions, injuries, outcomes, and patient management from point of wounding onward.

Because of the high numbers of injuries per casualty in both single and multiple body regions, Maximum AIS Military (MAIS-Military) was chosen as the simplest reliable method of estimating casualty mortality. MAIS has been shown to be an effective abbreviated method for assessing overall injury severity and probability of survival. It is the primary indicator of injury severity in vehicle crash injury research, is frequently used as a measure of injury severity in cases of multiple injuries, and is used in US Department of Transportation databases and analyses.[19,20]

Joint Theater Trauma Registry

As described by Jenkins et al.,[21] data collection begins at point of wounding and continues through definitive care. Trauma nurse coordinators collect data at combat support hospitals in the theater of combat operations (Level 3), data are forwarded with the casualty to the next level of care, and data collection by trauma coordinators continues at Landstuhl. All data are forwarded to the JTTR central site in San Antonio, TX, where they are abstracted, entered into a centralized database, and coded in AIS 2005-Military, AIS 2005, and International Classification of Diseases, 9th Revision, Clinical Modification (ICD 9-CM). Six of the coders at the JTTR central site are AIS injury coding specialists certified by the AAAM. Data for approximately 35,623 casualties (18,765 US military) have been entered into the JTTR as of April 6, 2009, representing 58% of US casualties injured between 2002 and 2008.

Navy-Marine Combat Trauma Registry

The Navy-Marine CTR collects and stores personal health information on US service members who receive initial care for battle and non-battle injuries, as well as disease and psychiatric events, at forward deployed Navy-Marine Corps medical treatment facilities (MTFs).[22] In OIF, forward care includes that rendered by first responders (self, buddy, or corps personnel), or at battalion aid stations (Level 1 care), shock-trauma platoons, forward resuscitative surgery systems, and surgical companies (all Level 2 facilities with surgical procedure capabilities). During the initial phase of combat in OIF (March 21–May 15, 2003), 23.5% of encounters at these MTFs were wounded in action (combat casualties) and 21% were non-battle injuries. The remaining 55.5% were disease and psychiatric encounters.[23] Data are collected on a standardized form that is part of the medical record, and forwarded with the casualty to each MTF. An additional copy is sent to the CTR headquarters at NRHC in San Diego, where the data are abstracted, entered into a computerized database, and coded using AIS 2005-Military, AIS 2005, and ICD-9-CM.

AFMES Mortality Trauma Registry

Injury data for all OIF and OEF combat decedents are provided to the JTTR by AFMES. Detailed autopsy results including wound path(s) for penetrating wounds for casualties killed in action before receiving medical care and those who die after receiving medical care (died of wounds) are linked with their corresponding data in JTTR. Four of the personnel preparing the data for the decedents are also AAAM-certified AIS coding specialists.

Wound Mapping

With casualty medical/autopsy records at hand, SWM users draw all surface wounds from a list of surface categories on a 3D digital body, code underlying injuries along wound tracts, code all other injuries using AIS 2005 and AIS 2005-Military, and link wounds to associated injuries based on information in the casualty medical record, thus producing an analyzable, visual representation of the data set. MAIS and the Injury Severity Score (ISS) are computer calculated for both AIS 2005-Military and AIS 2005. Each surface wound must have at least one associated injury, however, not all injuries are associated with a surface wound. Analysts then use SWAT to select cases based on demographic, wound, and injury characteristics. Images of wounds matching the search criteria are then overlaid on the digital body to form a density map, where different colors (keyed to a spectrum scale) are used to indicate the number of wounds occurring at any given point. For the SWM and SWAT analyses completed here, actual data were used but images had to be generated using test data because of security considerations.

Data Entry and Reliability

Each site has two or three data-entry specialists who have been working with the combat registry data for at least a year. They have been trained to abstract the wounds from the medical records and draw those wounds on the 3D body using surface and bone landmarks. Wounds are defined by a select list identified by surface category. The surface categories for which wounds can be drawn on the body include entrance and exit wounds, indeterminate wounds (wounds that cannot be identified as entrance or exit), peppering, partial or complete traumatic amputation, first- or second-degree burn, third- or fourth-degree burn, avulsion, blunt laceration, and crush. The focus of the data entry is on IED-associated wounds, particularly those with penetrating injury. Injuries associated with one or more wounds (identified in either the autopsy or medical record as located along the wound path) are linked using a Likert scale indicating the strength of the association as definitely, likely, or possibly associated with the wound path. For these analyses, only injuries with definite associations on the Likert scale were included in the queries.

Each site routinely reviews randomly selected cases among its data entry specialists to ensure that all are entering the data consistently. Select cases have been reviewed with combat trauma surgeons to ensure data quality. Each site also shares de-identified select cases with another site at predetermined times for data quality reviews. The other site reviews the record, enters the wounds, codes the injuries, and links injuries and wounds. These cases are then reviewed by all sites to evaluate consistency of data entry and to discuss issues encountered in the medical records. Decisions made at these reviews are recorded and shared with each site and added to the training.

RESULTS

In AIS 2005-Military, the severities of 356 injury descriptions were changed from their civilian counterparts in AIS 2005 (Table 2). Most changes (92%) entailed an increase in severity level of one increment (Table 3). The severity score was increased by two increments for each of 30 injury descriptions. Half (49%) of all changes occurred in the head region, followed by 15% in the neck, 10% in the cervical spine (there were no changes in the thoracic or lumbar spine), 9% in the lower extremities, 7% in the thorax, 5% in the upper extremities, 3% in the abdomen/pelvis, 1% in the face, and <1% external/burn/other trauma.

The increases occurred more frequently in the moderate to severe ranges (Table 3). A majority of the increases (41%) were from AIS 3 to AIS 4; 22% were from AIS 4 to AIS 5, and 21% were from AIS 5 to AIS 6. A total of 31 injury descriptions with AIS 6 remained unchanged in AIS 2005-Military, as did all 43 injury descriptions with AIS 9 (severity unknown).

Five examples of combat casualty injuries coded in both AIS 2005 and AIS 2005-Military are shown in Table 4 to illustrate the increased precision of the latter in characterizing combat trauma. Cases 1 and 2 show one-increment increases in severity and Cases 3, 4, and 5 show two-increment increases. Case 1 demonstrates the increased AIS severity in some injuries in the neck region. Many vessel, organ, and spinal cord injuries in this region have a one-increment increase in AIS 2005-Military severity. Case 2 represents increased severity for penetrating injuries that cross hemispheres, with the resulting increase in AIS 2005-Military from 5 (critical) to 6 (maximal). Cases 3, 4, and 5 are examples of specific injury descriptions with severity increases of two increments (from serious to critical) from AIS 2005 to AIS 2005-Military.

Data entry of sample Cases 1 and 2 in SWM are shown in Figures 1 and 2, respectively. Surface wounds are drawn on the 3D body, which can be zoomed in or out on the screen. The skin transparency can be increased in increments to allow visualization of underlying landmarks (Fig. 1, A). Injuries are linked with the associated wound as shown in Figures 1B and 2B. Data can then be queried in SWAT. In this example using test (not actual) data (see Methods), results in SWAT from querying entrance wounds to the head, neck, and torso with

TABLE 2. Increases in AIS 2005 to Produce AIS 2005-Military, by Body Region

AIS Body Region	AIS 2005 Severity Level	AIS 2005-Military Severity Level 2	3	4	5	6	Total Changes in Body Region
Head	AIS 2		3				
	AIS 3			63	17		174
	AIS 4				44	2	
	AIS 5					45	
Face	AIS 3			1	1		3
	AIS 4				1		
Neck	AIS 1	1					
	AIS 2		8	2			
	AIS 3			18	6		55
	AIS 4				15		
	AIS 5					5	
Thorax	AIS 1		1				
	AIS 3			13			
	AIS 4				7		26
	AIS 5					5	
Abdomen/pelvis	AIS 2		1				
	AIS 3			7			9
	AIS 4				1		
Spine (cervical only)*	AIS 3			11			
	AIS 4				7		36
	AIS 5					18	
Upper extremities	AIS 2		10				19
	AIS 3			8	1		
Lower extremities	AIS 1	1					
	AIS 2		4				33
	AIS 3			24			
	AIS 4				4		
External/burns/other	AIS 5					1	1
Totals		2	27	147	104	76	356

* There were no changes in severity in the thoracic or lumbar spine sections.

TABLE 3. Total Changes from AIS 2005 to AIS 2005-Military Severity Level

Increment Increase	Severity Level From AIS 2005	to AIS 2005-Military	Total
1	1	2	2
	2	3	26
	3	4	145
	4	5	79
	5	6	74
	Total with 1-increment increase		326
2	1	3	1
	2	4	2
	3	5	25
	4	6	2
	Total with 2-increment increase		30
		Total	356

TABLE 4. Sample Combat Cases Coded in AIS 2005 and AIS 2005-Military

Case	Injuries	AIS 2005	AIS 2005-Military	Increase in Severity Level
1	Penetrating fragment wound to the neck with transaction of right internal carotid artery	320212.4	320212.5	From 4 to 5
	Perforation of cervical esophagus	340108.4	340108.4	Unchanged
	Perforation of upper trachea	341608.3	341608.4	From 3 to 4
	Fracture of fourth cervical vertebra (C4) with cord contusion and incomplete cord syndrome	640214.4	640214.5	From 4 to 5
	MAIS	4	5	From severe to critical
2	Gunshot wound through and through the skull	116004.5	116004.6	From 5 to 6
	MAIS	5	6	From critical to maximal
3	Multiple cerebral contusions, NFS	140611.3	140611.5	From 3 to 5
	MAIS	3	5	From serious to critical
4	Panfacial fracture	251900.3	251900.5	From 3 to 5
	MAIS	3	5	From serious to critical
5	Vertebral artery (neck region); laceration; perforation; puncture; major; rupture; transection; blood loss >20% by volume	321012.3	321012.5	From 3 to 5
	MAIS	3	5	From serious to critical

AIS injury severity levels: (1) minor, (2) moderate, (3) serious, (4) severe, (5) critical, (6) maximal (currently untreatable), (9) unknown. NFS, not further specified.

AIS 2005-Military ≥3 injuries would produce the results shown in Figure 3. The scale (an ascending scale of severity from left to right/light to dark) shown in the density map indicates the number of wounds at given points on the body.

When actual data on these 1,151 patients, with 3,500 surface wounds and 12,889 injuries, were entered into SWM, surface wounds averaged 3.0 per casualty and internal injuries averaged 11.2 per casualty. Because of the emphasis on improving PPE, the analyses focused on the 2,496 (71%) of 3,500 wounds that were entrance wounds. The remaining 1,004 surface wounds were entered as other surface categories. The results of these analyses cannot be provided because of operational, security, and vulnerability issues.

Of 1,151 casualties, 654 (57%) lived and 497 (43%) died. The majority were men (97%) and injured in OIF (97%) and more than half (52%) were members of the US Army; see Table 5 for demographic distribution. Data for casualties injured between 2003 and 2006 were entered; however, the majority of the cases in this dataset were injured in 2004 (68%) and 2005 (24%) (Fig. 4). The majority of injuries (82%) were caused by explosions (Fig. 5).

Outcomes of the 1,151 patients were calculated using MAIS-Military. As shown in Figure 6, crude death rate increased along the continuum of severity from 3% to 85% between MAIS-Military 3 and 6. The MAIS-Military resulted in a slightly more precise prediction of outcome than did AIS 2005, however, more specific results of these analyses cannot be provided because of operational, security, and vulnerability issues. Casualty outcomes are displayed in Table 6. Five of the 1,151 casualties had AIS 9 as the only recorded severity; these cases were not included in the crude death rate calculations. As MAIS-Military increases, so does the average number of total injuries, from 5.6 for MAIS-Military 3 to 18.5 for MAIS-Military 6 (Table 7). For those with an MAIS-Military 5 or 6, the percentage of additional severe injuries is >68%. For each outcome, the numbers of persons, wounds, and associated injuries are listed in Table 8.

DISCUSSION

The AIS, especially its recent iterations of AIS 2005 and AIS 2005-Military, remains the cornerstone of anatomic injury characterization and the foundation of future efforts. Data for approximately 10,000 casualties in the legacy databases (WDMET, etc) have now been coded in AIS 1998, AIS 2005, and AIS 2005-Military. Similar efforts are almost complete for approximately 10,000 casualties from the current conflicts.

TABLE 5. Patient Demographics (N = 1,151)

	No. (%)
Gender	
Male	1,114 (97)
Female	27 (2)
Not documented	10 (<1)
Service	
US Army	603 (52)
US Marines	351 (30)
US Navy	22 (2)
US Air Force	1 (<1)
Not documented	174 (15)
Operation	
OIF	1,121 (97)
OEF	16 (1)
Not documented	14 (1)

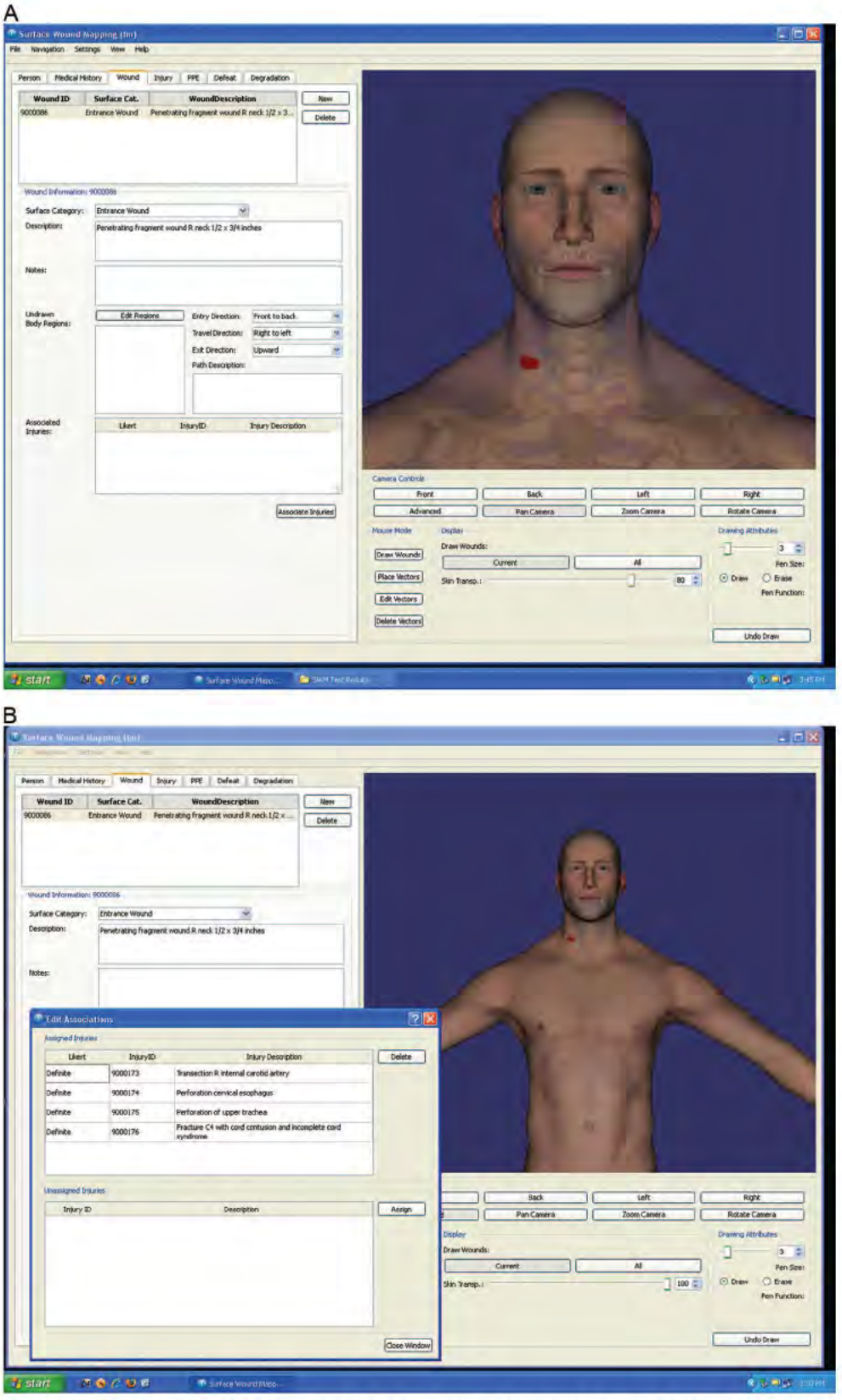

Figure 1. Case 1: Sample data entry in SWM (test data). *A*, Penetrating fragment wound to the right neck with skin transparency increased to view underlying structures. *B*, Penetrating fragment wound to the right neck with associated injuries.

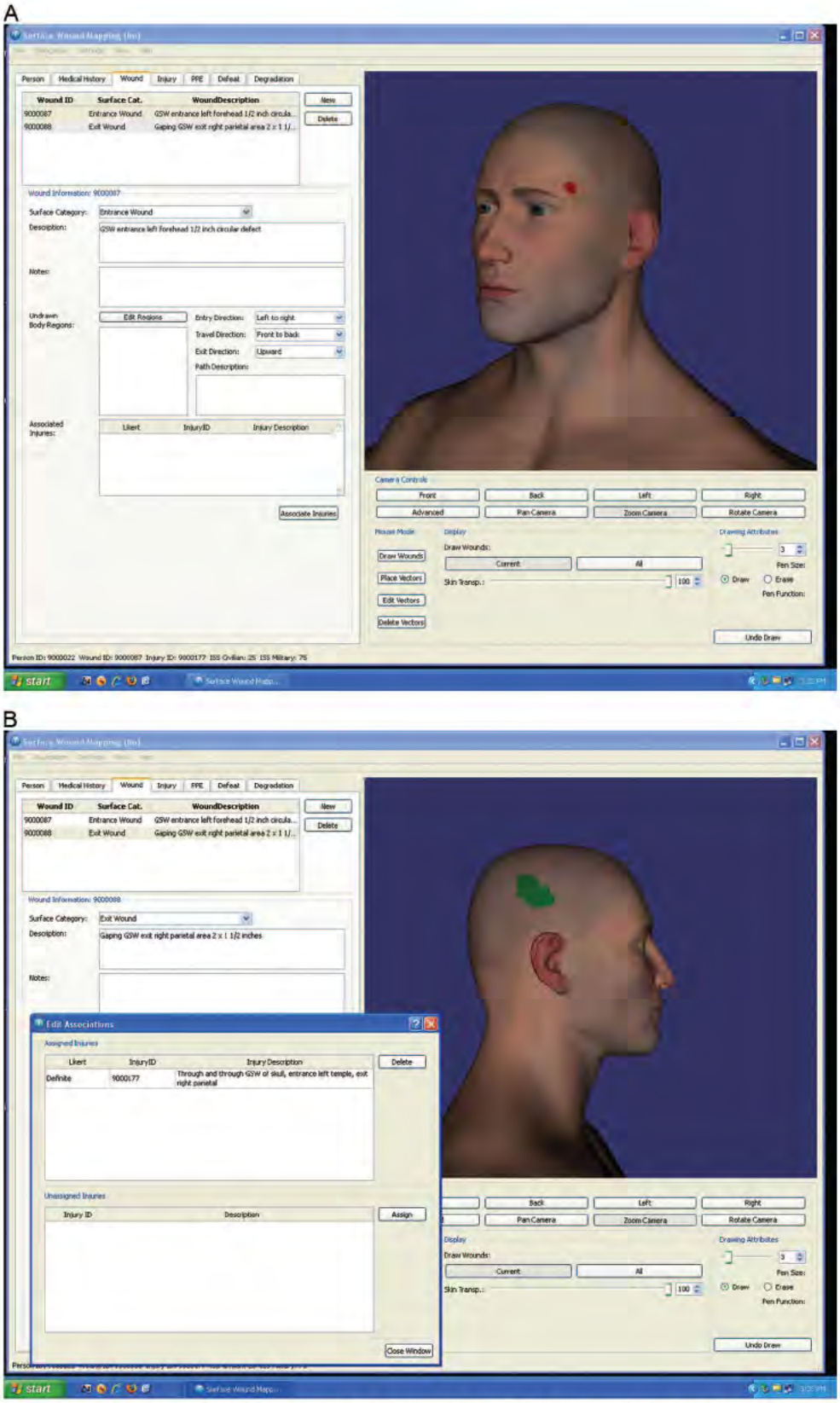

Figure 2. Case 2: Sample data entry in SWM (test data). *A*, Gunshot wound entering the left forehead. *B*, Gunshot wound exiting the right parietal area with associated injuries.

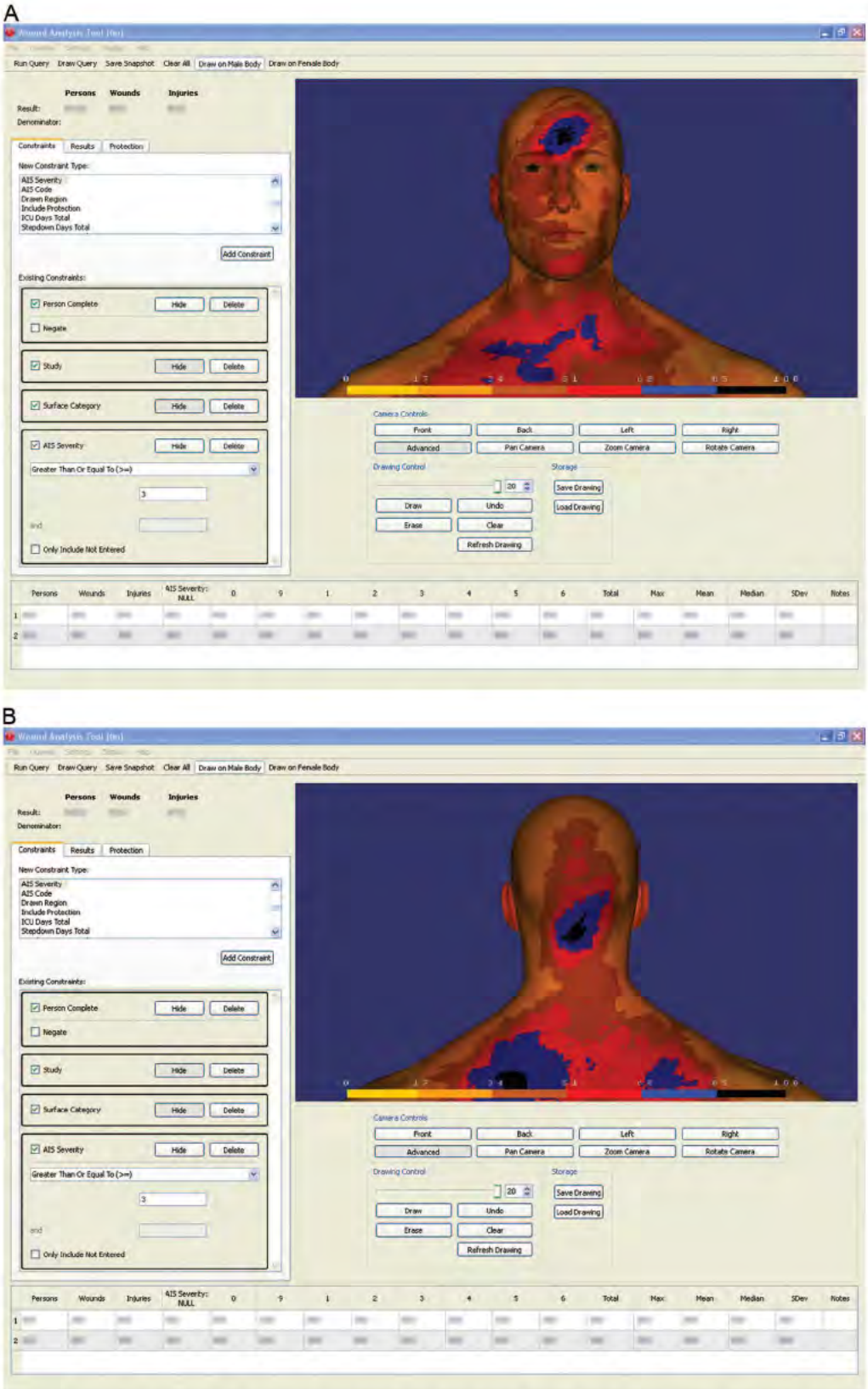

Figure 3. SWAT query: density map of all entrance wounds to the head, neck, and torso with AIS 2005-Military ≥ 3 injuries (test data). *A*, Anterior view (test data). *B*, Posterior view (test data).

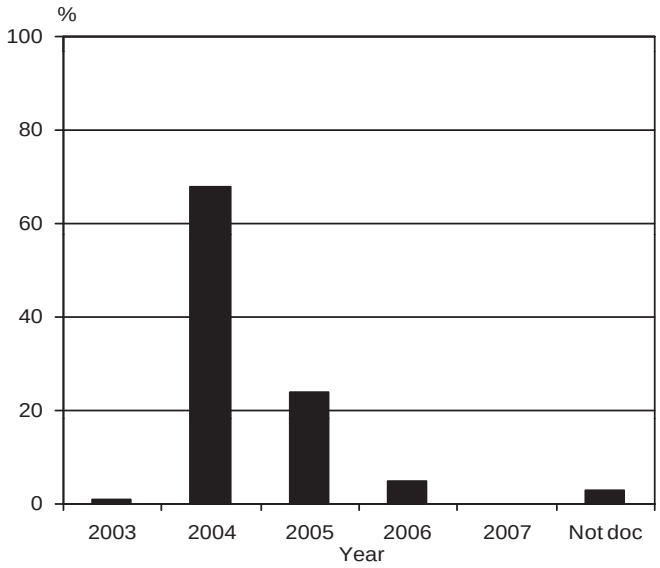

Figure 4. SWM data distribution by year: 2003–2007.

SWM and SWAT represent significant advances in combat casualty databasing and analysis. Data elements pertaining to PPE, vehicles, and the tactical environment have been added (in a secure environment). SWM now contains data on more than 2,406 patients, with an emphasis on torso, junctional, and head and neck injuries. As such, the database represents about 15% of those severely injured or killed since OEF and OIF started and thus is more than twice the size of the sample of patients from the Vietnam War in WDMET and has many more capabilities. SWAT functionality allows for visual display of density maps showing damage to PPE (in the same manner as surface wounds), and for individual case review, and aggregated results. These will enable quality of care assessment and facilitate future PPE modifications by the engineers. Future modifications to PPE must balance weight and mobility for the soldier. Improvements being considered include tailoring for mission specificity (e.g., different PPE for individuals on foot patrols or in armored vehicles). Another modification may include changes to PPE based on anthropomorphic data. SWAT analyses will provide additional data to PPE and vehicle designers, epidemiologists; combat casualty care planners; tactics, techniques, and procedures developers; and analysts concerned with vehicle occupant survivability that they have not had access to in the past.

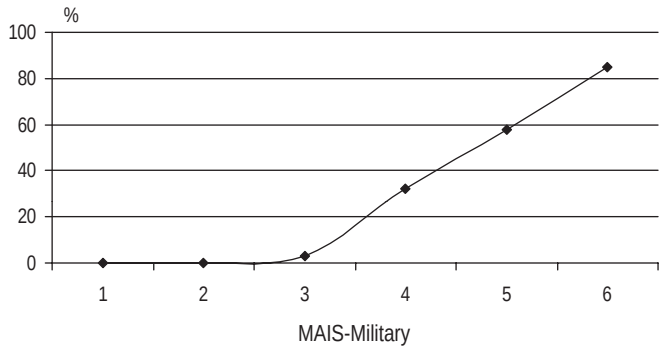

Figure 6. Crude death rate calculated using MAIS-Military.

CONCLUSION

By using AIS 2005-Military, these new tools—SWM and SWAT—have been successfully implemented to describe combat injury, mortality, and distributions of wounds and associated internal injuries. They are being used in quality of care assessments and to direct resources for optimal care, training activities, and research. They are also providing

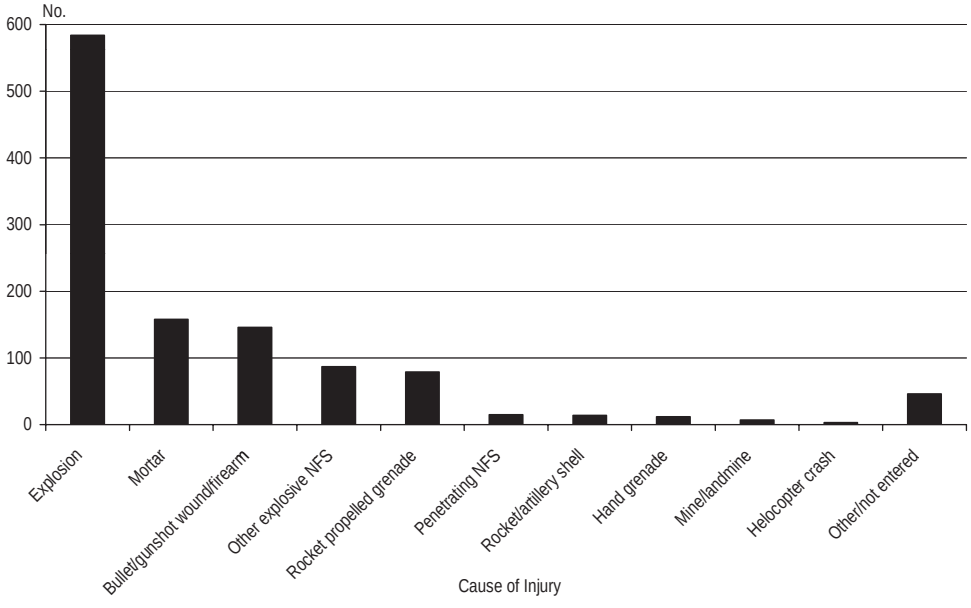

Figure 5. Cause of injury. NFS, not further specified.

TABLE 6. Outcomes Among OIF and OEF Casualties Calculated Using MAIS-Military

	MAIS-Military						
Outcome	**1**	**2**	**3**	**4**	**5**	**6**	**Totals**
Killed, N (%)	0	0	6 (3)	48 (32)	144 (58)	297 (85)	495 (43)
DOW	0	0	4	32	69	63	168
KIA	0	0	2	16	75	234	327
Wounded, N (%)	90 (96)	114 (95)	174 (93)	100 (68)	103 (41)	52 (15)	633 (55)
WIA	83	113	173	98	102	52	621
RTD	7	1	1	0	0	0	9
Unknown/NE	4	6	6	0	3	2	21 (2%)
TOTAL, N	94	120	186	146	249	353	1,146*

DOW, died of wounds; KIA, killed in action; WIA, wounded in action; RTD, returned to duty; NE, not entered.
* Five casualties had AIS 9 as the only injury severity and were not included in the crude death rate calculations.

TABLE 7. Injuries by MAIS-Military and Associated Additional Injuries

			At Least One Additional AIS 2005-Military Injury		
MAIS-Military	**N**	**Average Total Injuries**	**3**	**4**	**5**
3	186	5.6			
4	146	8.6	103 (70%)		
5	249	13.4	169 (68%)	183 (73%)	
6	351	18.5	239 (68%)	274 (78%)	277 (79%)

TABLE 8. Distribution of Persons, Wounds, and Injuries by Outcome

	Killed		Wounded			
	DOW	**KIA**	**WIA**	**RTD**	**NE**	**Total**
N	168	329	624	9	21	1,151
Wounds	524	1,480	1,403	19	74	3,500
Injuries	2,325	6,819	3,584	21	140	12,889

DOW, died of wounds; KIA, killed in action; WIA, wounded in action; RTD, returned to duty; NE, not entered.

additional data for those researching improvements in personnel/vehicle protection, injury outcomes (both immediate and over time), resource management, functional impairment, and long-term planning. The dataset presented here is a convenience sample biased toward torsal, head and neck, junctional, and explosion-related injuries. This resulted from the primary motivation for the projects to create databases that would provide value-added information to protect warfighters from IEDs. As a consequence, the database focuses on casualties with more severe injuries.

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