Military Trauma Care's Learning Health System: The Importance of Data Driven Decision Making

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Commissioned by the National Academies of Sciences, Engineering, and Medicine Committee on Military Trauma Care's Learning Health System and Its Translation to the Civilian Sector

Table of Contents

EXECUTIVE SUMMARY

The National Academies of Sciences, Engineering, and Medicine Committee on Military Trauma Care's Learning Health System (LHS) and its Translation to the Civilian Sector was tasked with characterizing the Department of Defense (DoD) Joint Trauma System (JTS), and the DoD Military Health System (MHS) trauma research program investment, and their integrated role as a continuous learning and evidence-based process improvement model. Opportunities were examined to ensure that the recent advances in trauma care developed by the DoD from experiences gained during the conflicts in Afghanistan (2001-2014) and Iraq (2003-2010) were sustained and built upon for future military combat and overseas contingency operations. Needed strategies were considered to more effectively translate knowledge and practice from the military's LHS to the civilian health sector and vice versa.

The committee commissioned this paper, **"Military Trauma Care's Learning Health System: The Importance of Data Driven Decision Making"**, to better understand the processes by which trauma data are collected, analyzed, and applied to guide decision making at the system and patient levels in both the military and civilian sectors. This paper was submitted to inform the committee's deliberations on opportunities for enhancing data collection and analysis in the context of a LHS for trauma care that informs all key stakeholders, supports better decision making, and improves patient outcomes.

Specifically, this paper reviewed the current state of data collection and distribution in both military and civilian trauma systems, and described the processes by which these data are analyzed and transformed into actionable information that can be used to effect system-level changes in care. Included are descriptions of how clinical practice guidelines (CPGs) are created, maintained, and promulgated across the systems, and current mechanisms to evaluate adoption of these CPGs as well as the impact of their implementation on clinical outcomes. Identified were gaps caused by current practices in data collection, distribution, and use that, if addressed, could improve trauma care and patient outcomes. Included are discussions on challenges inherent with the collection, sharing, and integration of trauma and related cost data across the different levels of care (point of injury, transport, acute care, and rehabilitation) and different medical facilities, including lack of platform interoperability as well as political, commercial and regulatory barriers (both real and perceived). Examined were barriers and approaches to overcome them to address gaps and maximize timely access to critical data. Described are how and where needed data should be collected and what entities should be responsible for collecting it. This includes data needed to perform all types of comparative effectiveness research; to adequately risk adjust patients for appropriate comparison between military medical treatment facilities (MTFs) and/or civilian trauma centers; to determine cost-effectiveness of practice changes; and to evaluate outcomes in the military and civilian settings based on metrics that include morbidity and

mortality but also include other potentially important outcome measures, particularly patient reported outcomes (i.e. pain, physical function). Provided are specific examples (e.g., tourniquet use, tactical combat casualty care, transport and en route care, damage control resuscitation) that can be used to highlight how trauma data has been used in a LHS approach to inform and enable timely and appropriate decision making. We also highlight the opportunities to augment medical professional decision making capabilities via the use of clinical decision support tools which can optimize clinical care and ensure all injured patients receive the best care available.

The creation and development of a DoD Joint Trauma System and DoD Trauma Registry, modeled after efforts found in the civilian sector (the American College of Surgeons National Trauma Data Bank [NTDB] and the National Emergency Medical Services Information System [NEMSIS]), has proved to be one of the most significant innovations in military medicine over the past decade. Comprehensive performance improvement through globalization of best practices and continuous learning through trauma system failures, found in the details of trauma morbidity and mortality, have significantly helped to inform leaders and guide trauma care delivery in both the civilian and military arenas. However, for both the military and civilian sectors, notable gaps continue to exist in trauma system data collection. Barriers to progress and performance improvement reside in the realms of leadership decision making, prioritization of funding, optimization of electronic health records and data abstraction for registries, and regulations for patient confidentiality.

Continued advancement of trauma care delivery and improvement of trauma outcomes resides in the commitment, priority, and decision making of leaders to do such. Data collection must be comprehensive and integrated from every level of a trauma system. We must ensure interoperability of electronic health records and registries between trauma systems, in order to afford immediate access to full patient records and data in real time to any clinician caring for an injured patient. Data is paramount for analyzing and understanding the entirety of a system, differences and similarities between systems, individual patient requirements, and unique aspects of individual patient care found in differing environments and from differing mechanisms of injury. These needs must be addressed through performance improvement, clinical practice guidelines, training and education, and research and technology. Trauma care delivery must be continuously improved through an institutional commitment and within an organizational culture of safety and a construct of eliminating preventable morbidity and mortality and optimizing functional recovery. Although critically important to safeguard classified military information and protect the rights of human subjects, it is equally important to use all available existing clinical patient data to drive improvement. Current regulations may need to be re-examined to maximize the benefit from research while simultaneously maintaining operational security and minimizing risk to patients considered research subjects.

Our efforts should be driven by science. We must first use data to perform all types of comparative effectiveness research to create new knowledge of what works well for both individual patients and systems of care. Then, we must take every opportunity to ensure that patients receive the optimal care they deserve. These approaches include writing and disseminating CPGs. However, education alone is rarely the answer. Thus, we must build smarter systems that prompt clinicians to provide specific treatment plans based on individualized patient characteristics, whether they be simple demographics or based on advanced biomarkers, in order to fulfill the promise of personalized medicine. We must also embrace the developing field of knowledge translation and use scientific principles to propagate successful efforts from small pockets of excellence to the civilian and military health systems as a whole.

INTRODUCTION

Innovation and advancement of best practices in medicine are often translated throughout communities during times of heightened awareness to include war, epidemics, or other urgent threats to humanity. However, this evolution and translation process has sometimes taken decades before it has fully benefited both our civilian and military communities.

Historically, our Nation's trauma and emergency medical system infrastructure has improved considerably during and after a period of war. Numerous advancements in medical care have resulted from lessons learned, performance improvement efforts, and research directly translated back and forth between civilian and military health systems. Many aspects of our current U.S. civilian trauma systems were derived from military lessons learned from the Vietnam and Korean conflicts. Subsequent studies over the past 40 years have demonstrated that trauma outcomes in the U.S. were greatly improved through trauma center and trauma system development. **(Mann 1999, MacKenzie 2006)** These civilian trauma system lessons learned were then translated back to the military with the creation of a formal military trauma system, the Department of Defense (DoD) Joint Trauma System (JTS), in 2004.

The JTS was developed to provide a structured approach to the organization, integration, and coordination of the entire continuum of trauma care provided to military casualties, from point of injury through rehabilitation, and to enable an operational cycle of trauma care delivery and performance improvement through a trauma registry that would rapidly optimize trauma care protocols, procedures, and CPGs in order to ultimately improve resultant outcomes of morbidity and mortality. The JTS had four simple tenets of "right patient, right place, right time, and right care," and a guiding vision of optimizing survival and functional recovery. **(Eastridge 2006)** The JTS subsequently used contemporary systems-based methodologies to foster advances in military medicine, which included the creation of a formal trauma registry, the Department of Defense Trauma Registry (DoDTR).

EPIDEMIOLOGY OF TRAUMA PATIENTS AND OUTCOMES

Global Impact of Trauma

In accordance with the World Health Organization (WHO), "Injuries and violence have been neglected from the global health agenda for many years, despite being predictable and largely preventable." Worldwide, more than five million people die from injuries and tens of millions of people suffer non-fatal injuries every year. Approximately a quarter of the five million deaths from injuries are the result of suicide and homicide, while road traffic injuries account for nearly another quarter. Other main causes of death from injuries are falls, drowning, burns, poisoning, and war. Injuries account for 9% of global mortality, nearly 1.7 times the number of fatalities that result from HIV/AIDS, tuberculosis, and malaria combined. Every six seconds someone in the world dies as a result of an injury. Every day more than 14,000 people die as a result of an injury. There are few global estimates of the cost of injury, but the following example illustrates the financial impact of injuries on national economies and individual families: Road traffic deaths and injuries cost approximately 2% of gross domestic product in high-income countries and as much as 5% of gross domestic product in some low- and middle-income countries. These costs include medical bills, vehicle damage, and lost productivity and total around US$ 1.9 trillion a year globally. **(WHO 2015)**

U.S. National Impact of Trauma

In accordance with the Center for Disease Control and Prevention (CDC) and the National Trauma Institute (NTI), the number of emergency department visits for injuries in the U.S. was 43.0 million in 2011; the number of all injury deaths in the U.S. in 2013 was 192,945 (60.2 deaths per 100,000 population); the number of motor vehicle traffic deaths in the U.S. in 2013 was 33,804 (10.7 deaths per 100,000 population); and the number of all firearm deaths in the U.S. in 2013 was 33,636 (10.6 deaths per 100,000 population). In 2014, the estimated economic burden of injuries in the U.S was approximately US$ 585 billion a year, which included both health care costs and lost productivity. Currently, injuries are ranked as the number one cause of death for age group 1-46, and accounts for 47% of all deaths in this age range. Additionally, injuries are ranked as the number three leading cause of death overall across all age groups. Because trauma is a disease affecting all ages of people, the impact on life years lost is equal to the life years lost from cancer, heart disease and HIV combined. In 2014, trauma injury accounted for 30% of all life years lost in the U.S.; whereas cancer accounted for only 16%, and heart disease only 12%. **(Rhee 2014, CDC 2015, NTI 2015, WISQARS 2015)**

U.S. Military Combat Trauma

In accordance with the Defense Manpower Data Center, Defense Casualty Analysis System, 623,537 U.S. military personnel have died in war and major conflicts over the past century. Additional details for U.S. casualties from war and major conflicts are shown in **Table 1**. **(DCAS 2015)**

Table 1 Number of U.S. Casualties from War and Major Conflicts, Defense Casualty Analysis System, as of September 18, 2015.

War or Conflict	Mortal Injury (Battle / Non-Battle)	Non-Mortal Injury
Afghanistan (OEF, OFS)	2351 (1843 / 508)	20,071
Iraq (OIF and OND)	4477 (3519 / 958)	32,246
Vietnam	58,220 (47,434 / 10,786)	153,303
Korea	36,574 (33,739 / 2835)	103,284
World War II	405,399 (291,557 / 113,842)	670,846
World War I	116,516 (53,402 / 63,114)	204,002

Abbreviations: Operation Enduring Freedom, OEF; Operation Freedom's Sentinel, OFS; Operation Iraqi Freedom, OIF; Operation New Dawn, OND.
Note: Operation Enduring Freedom includes actions in Pakistan, Kyrgyzstan, Philippines, Horn of Africa, Trans-Sahara, Caribbean and Central America.

During the attacks on the World Trade Center and the Pentagon on September 11, 2001, approximately 3,000 Americans died; however, more than 3,000 Americans currently die from

trauma in the U.S. every week. During the combined fourteen years of war in Afghanistan and Iraq from 2001 to 2015, approximately 7,000 Americans died; however, more than 7,000 Americans currently die from trauma in the U.S. every two weeks. As more than 192,000 Americans died from trauma in the U.S. within one year, more Americans will have died in the U.S. within four years than in war and major conflict over the past century.

Trauma Care Translation and Performance Improvement

As the historic and current burden of morbidity and mortality in both the civilian and military sectors substantially result from trauma, do both sectors have appropriate and commensurate mandates, monies, and manpower dedicated toward prevention, performance improvement, research, training, and policy-making on behalf of this leading cause of death? Or, have priorities of policy-makers, researchers, and practitioners become influenced and distorted by advocacy and emphasis on disease processes that result in less morbidity and mortality in comparison to trauma and injury?

Research programs and training programs designed to improve trauma care delivery will have the greatest impact if its goals follow the priorities set forth through a comprehensive performance improvement review of trauma system failures. These areas of improvement can be found in the details of morbidity and mortality. Over the past decade, DoD accomplishments through data collection and analysis, performance improvement initiatives, and combat casualty care research have led to the fielding of safe and effective extremity and junctional tourniquets, improved hemostatic dressings, advanced damage control resuscitation procedures, and prehospital and hospital clinical practice guidelines (CPGs) that have dramatically improved trauma care and morbidity and mortality on the battlefield. However, has the DoD successfully institutionalized, disseminated, and integrated requirements and funding for these accomplishments through doctrine and policy in order to firmly establish a trauma system and trauma registry, and ensure mission success through personnel, training, and equipment levels that meet current needs and future readiness efforts? Have we rapidly translated these accomplishments and lessons learned throughout the military and to the civilian sector where appropriate? Do we expect state-of-the-art trauma care for our populace in urban as well as isolated areas of rural America? Should we expect state-of-the-art trauma care for our service members during a firefight in an austere environment located in a country thousands of miles away?

BENEFITS GAINED THROUGH IMPROVEMENT OF A TRAUMA LEARNING HEALTH SYSTEM (LHS)

Quality Improvement through Structure, Process, Outcomes

Avedis Donabedian is often credited as suggesting the best known conceptual framework for quality improvement work in medicine. He suggested that all quality can be scientifically studied by examining one of the following three domains: Structure, Process, Outcomes. **(Donabedian 1988)** The structure is defined by the National Quality Measures Clearinghouse as "*a feature of a healthcare organization or clinician related to the capacity to provide high quality health care.*" **(USDHHS AHRQ NQMC 2015-1)** Structural elements include the physical (i.e. buildings, equipment) and human (i.e. physician, nurse) resources available. It also includes organizational domains such as the existence of protocols and/or guidelines. These

measures focus on the relatively "fixed" attributes of a hospital which impact its ability to deliver high quality care. Structure is usually defined as a hospital-level (as opposed to patient-level) characteristic. Process measures can be defined as "*a health care-related activity performed for, on behalf of, or by a patient.*" **(USDHHS AHRQ NQMC 2015-2)** A process measure is usually defined as applying on an individual patient level. Outcomes can be defined as "*a health state of a patient resulting from health care.*" These may include clinical outcomes (i.e. mortality, morbidity, complications) or patient reported outcomes (i.e. symptoms, quality of life). **(USDHHS AHRQ NQMC 2015-3)** Recently, a large-scale evaluation of the trauma care in a single Canadian province used this framework explicitly and found significant correlations between quality domains and led the authors to state "that Donabedian's structure-process-outcome model is a valid model for evaluating trauma care." They showed that "trauma centers that perform well in terms of structure also tend to perform well in terms of clinical processes, which in turn has a favorable influence on patient outcomes." **(Moore 2015)**

Quality Improvement and the ACS-COT

Within the trauma community, the American College of Surgeons (ACS) has the most rigorously developed and accepted nationwide criteria for delivering trauma care in a robust comprehensive trauma system. The ACS was founded in 1913. The ACS formed the Committee on Fractures in 1922, which then merged with the Committee on Industrial Medicine and Traumatic Surgery to form the Committee on Fractures and Other Trauma in 1939, and then ultimately adopted its current name, Committee on Trauma (ACS-COT), in 1950. This committee has been instrumental in using data to improve trauma care on both a national and international scale for decades. For many years the ACS-COT has published the "Resources for Optimal Care of the Injured Patient", now in its 6th edition. **(ACS 2015)** This reference book is the framework behind the ACS-COT trauma center verification program which has verified over 400 trauma centers nationwide.

The ACS-COT focuses on the three domains of quality improvement as first suggested by Donabedian. This manual describes the required structure to be a trauma center of a certain level. For example, structural includes staffing requirements (i.e. numbers of surgeons and their required training), physical plant requirements (i.e. availability of radiology equipment and operating rooms), and administrative structure (i.e. Trauma Surgeon as ICU Director). The Optimal Resources manual gives guidance on process of care that should be delivered to injured patients. Some of these processes delineate what should be done for EVERY patient (i.e. trauma surgery attending will be present in the emergency department within a pre-specified time) while others apply only to a subset of patients based on individual characteristics, (i.e. only apply to patients with a specific injury or severity). For example, patients with Glasgow Coma Scale (GCS) score of less than 8 should be intubated and mechanically ventilated and should all receive a computed tomography (CT) scan of the head. In theory, as the systems and processes of care improve, clinically important outcomes will improve. In the field of trauma care, numerous studies have shown this to be the case. For example, multiple papers have demonstrated the improvement in processes and resultant outcomes after introduction of a more formalized trauma center or new verification. **(Cornwell 2003, Simons 1999)** Others have shown that the effects of the trauma system can overcome the inexperience of individual trauma surgeons **(Haut 2009)** Perhaps the most robust project to show improved outcomes of trauma center care was The National Study on the Costs and Outcomes of Trauma Care (NSCOT), funded by the CDC and

National Institutes of Health (NIH). This project showed that "risk of death is significantly lower when care is provided in a trauma center than in a non-trauma center." **(MacKenzie 2006)**

Quality Improvement and the Example of CLABSI

One of the most successful examples of quality improvement on an international scale is the work by Peter Pronovost to decrease the incidence of central line-associated bloodstream infection (CLABSI) in the intensive care unit (ICU). Decades ago, some rate of CLABSI was considered acceptable and most ICU physicians agreed that it was simply the "cost of doing business" and an unavoidable complication. Pronovost challenged these assumptions but his initial suggestion that CLABSI could be eliminated was met with skepticism. He persisted and provided data, first from a single ICU **(Berenholtz 2004)** and then from an entire state collaborative **(Pronovost 2006)**, that these infections can be nearly 100% eliminated by use of a simple checklist. This checklist is now routinely used around the world and numerous studies have shown associated improvements in infection and mortality. His persistence and use of reliable data was able to convince an entire generation of intensivists that CLABSI can and should be nearly eliminated.

Quality Improvement and Trauma Systems

This same concept is applied to trauma systems as well. Trauma registries have been a standard part of civilian trauma system development for decades. In fact, many of the early leaders in use of data to improve care were trauma surgeons.

This understanding of the importance of data was embraced by the trauma community decades before others agreed with the concept. The Major Trauma Outcomes Study (MTOS), led by Howard Champion was the first large scale attempt to examine outcomes of care for injured patients. During the 1980s, 139 North American hospitals submitted demographic, etiologic, injury severity, and outcome data on more than 80,000 injured patients. **(Champion 1990)** Critical to the success of the project was the understanding that some sort of scoring system should be used to compare injury severity between patients. During that time, a variety of scoring systems had been proposed to scale the level of both anatomic and physiologic injury.

Anatomic and physiologic injury severity scoring systems have been created in an attempt to quantify (and standardize) injury severity assessment among trauma patients. Without these tools, benchmarking trauma care and comparing outcomes would be impossible, or worse, lead to flawed inferences. Some measures rely on a careful evaluation and abstracting clinical data from an individual patient's medical record. Others utilize administrative/billing healthcare data and convert into anatomic injury scores or risk of death (or disability) from injury. A detailed description of some of the most common injury severity scoring systems may be found in **Appendix II**.

U.S. National Trauma Data Bank

Within the ACS-COT, the massive conglomeration of data into a large aggregated registry that began as the MTOS has morphed into the National Trauma Data Bank (NTDB). The NTDB began in 1999 and now is the "largest aggregation of U.S. trauma registry data ever assembled." It has amassed over 6 million patient records from over 700 hospitals. Although originally begun as a voluntary process, the ACS-COT now includes submission of data to the NTDB as a required structural element of the trauma center verification process. Variation

related to voluntary complication reporting in the early days of the NTDB was shown to produce misleading benchmarking of complications between trauma centers. **(Kardooni 2008)** Data quality within the NTDB has dramatically improved since the adoption of the National Trauma Data Standard (NTDS) in 2007. The NTDS rigorously defines standardized data elements to avoid variability in data abstraction and reporting between trauma centers. This standardized dataset includes only core variables that would prove useful if aggregated on a national level. The NTDB is a critical part of the growing ACS-COT Trauma Quality Improvement Program (TQIP). This large quality improvement collaborative is using reliable, high-quality data as the backbone to improve trauma care.

In 2014, the ACS and the DoD Military Health System (MHS) formed the Military Health System Strategic Partnership American College of Surgeons (MHSSPACS) to improve educational opportunities, systems-based practices, and research capabilities in surgery. However, despite the fact that trauma and battlefield care is the quintessential mission of military medicine, **(Mabry 2014)** currently less than 10% of U.S. military hospitals are trauma centers, only a few are verified by the ACS-COT (Level I-San Antonio Military Medical Center, Level II-Walter Reed National Military Medical Center, Level III-Landstuhl Regional Medical Center in Germany), and only a single site participates in the ACS-TQIP level III pilot."

Combat Casualty Care Statistics

Military and civilian casualty data are specific to the context in which it occurs. Differences, to include historical time period, weaponry, medical capability, weather, geographic region, permissive versus nonpermissive environments, and population at risk may not permit specific inferences for predicting future casualty event outcomes; however, expectations can be formed from previous observations, and general comparisons can be made between casualty events in terms of medical care and evacuation as well as outcomes of morbidity and mortality.

Military combat casualties include both Battle Injuries (BI) and Disease and Non-Battle Injuries (DNBI). Although the lexicon may vary between military services, the medical literature have provided common definitions, statistics, epidemiology, and outcome terms for Battle Injuries (BI) so as to better interpret combat trauma data, to provide metrics and insight into the effectiveness of both prehospital and hospital trauma care, and to guide strategies that will improve combat casualty care. **(Bellamy 1984, Holcomb 2006)** The total aggregate of BI combat casualties includes both those who are wounded in action (WIA) and those who are killed in action (KIA). Thus, BI = WIA + KIA.

Those who are Wounded in Action (WIA) include all BI combat casualties who were not Killed in Action (KIA). Thus, WIA = RTD + (Non-DOW & Non-RTD) + DOW. Returned to Duty (RTD) are those who received care for wounds but who return to duty within 72hrs of injury; Died of Wounds (DOW) are those who died after arriving at a Medical Treatment Facility (MTF); and Killed in Action (KIA) are those who died before reaching a MTF. The traditional definition of MTF includes facilities found at all military roles of medical care: Role 1 (e.g. battalion aid station), Role 2 (e.g. forward surgical team), Role 3 (e.g. combat support hospital), and Role 4 (e.g. continental U.S. full-service hospital). **(Holcomb 2006)** However, a recent variance noted in the literature does not include Role 1 facilities in the definition of MTF as these facilities are prehospital entities that lack true major surgical capability. **(Kotwal 2015)**

Standard combat casualty care statistical definitions include: 1) %Returned to Duty ≤72hrs (%RTD) = [RTD/WIA x 100] which defines minor wounds; 2) %Killed in Action (%KIA) = [(KIA/(KIA + (WIA – RTD)) x 100] which provides a potential measure of weapon

lethality, effectiveness of prehospital medical care, and availability of prehospital transport; 3) %Died of Wounds (%DOW) = [(DOW/(WIA – RTD)) x 100] which provides a potential measure of the precision of initial prehospital triage and care, optimization of evacuation procedures, and application of a coordinated trauma system, as well as the effectiveness of medical treatment facility care; and 4) Case Fatality Rate (CFR) = [(KIA + DOW)/(KIA + WIA) x 100] which provides a potential measure of overall battlefield lethality in a battle injury population. **(Bellamy 1994, Holcomb 2006)**

Caution must be used when reviewing KIA and DOW rates. The longer that severe and critically injured casualties remain in the prehospital battlefield environment, the more likely they will die and be categorized as KIA. **(Bellamy 1984)** Hospitals that use DOW rates as a metric, and tout low DOW rates in isolation from other rates, may not be truly reflecting the opportunity to receive care provided in hospitals; rather, these data may be reflective of delayed transport and casualties not arriving to a hospital to benefit from the full measure of the trauma system.

The success of a trauma system can be measured through lives saved. Lives saved is directly related to improvements in medical care and evacuation. Combat casualty care statistics can provide comparisons within a conflict, **(Kelly 2008, Kotwal 2011, Kotwal 2015)** as well as between conflicts. **(Holcomb 2006, Kotwal 2015)** These statistics provide a foundation for overall understanding of combat trauma data and also denote 'where' medical care and evacuation can be improved, as KIA deaths occur in the prehospital environment and DOW deaths occur in the hospital environment. Historically, emphasis has been placed on improvement of hospital efforts on behalf of those who are in the DOW category; with less attention paid to prehospital efforts that could benefit the much larger KIA category. **(Maughon 1970, Bellamy 1984)** Comprehensive studies conducted on deaths during recent conflicts in Afghanistan and Iraq show that progress has been made; however, the most substantial improvement in survival can still be realized through prehospital efforts. **(Eastridge 2011-2, Eastridge 2012)** Unfortunately, the historical lack of prehospital combat data makes performance improvement during this phase of care difficult. **(Eastridge 2011-1, Kotwal 2013-2, Kotwal 2015)**

Military Preventable Trauma Death Studies

Use data to understand the extent and nature of injuries. Research the causes of particular injuries of interest. Develop strategies to address the causes and evaluate the effects of these measures. Put into place effective prevention programs.

Combat deaths can be prevented through: 1. Primary prevention, which is prevention of injury incident through policy; tactics, techniques, and procedures (TTPs); and evidence-based findings from tactical After Action Reviews (AARs) and medical (prehospital, hospital, rehabilitation) AARs and registry data; 2. Secondary prevention, which is mitigation of injury extent through tactical contingency planning and Personal Protective Equipment (PPE; e.g. military through helmet, eye pro, body armor; civilian through seat belts and air bags for cars, helmets for motorcycles); and 3. Tertiary prevention, which is optimization of injury care through clinical practice guidelines (CPGs), properly executed prehospital care, optimized tactical casualty response at point of injury and during evacuation, forward or early damage control resuscitation and damage control surgery, and optimized hospital decision making (e.g. initial care at a small forward facility vs a large robust facility; initial care in the emergency

room vs direct to surgery; provide care in the ICU vs the ward; inpatient vs outpatient rehab). **(Kotwal 2013-1)**

Both convenience sample **(Holcomb 2007, Kelly 2008)** and comprehensive preventable death studies **(Eastridge 2011-2, Eastridge 2012)** that categorize fatalities as medically non-survivable (NS) or potentially survivable (PS) have great value for 'what' medical care can be improved, particularly if they specify mechanism of injury, distribution of wounds by anatomical location, cause of death, and care provided or not provided. As all U.S. combat casualty deaths are recovered when feasible and transported to the Armed Forces Medical Examiner System (AFMES) at Dover Air Force Base, Delaware, for a comprehensive forensic examination and entry into the Mortality Trauma Registry (MTR), population death analyses can be conducted for trends and opportunities for performance improvement.

An expert panel conducted a convenience sample review of U.S. Special Operations Forces combat fatalities (n=82) between October 2001 and November 2004, which showed that 85% (70/82) of the deaths were categorized as NS and 15% (12/82) were PS. **(Holcomb 2007)** Another expert panel conducted a comprehensive review of battlefield fatalities (n=4,596) between October 2001 and June 2011, which depicted 87.3% of all injury mortality occurred in the pre-MTF environment, which is relatively unchanged from the 88% noted from the Vietnam conflict. **(Bellamy 1984)** Of the pre-MTF deaths, 75.7% (3,040/4,596) were categorized as NS and 24.3% (976/4,596) were PS. Of those who were PS, 90.9% (888/976) were associated with hemorrhage or hemorrhagic shock. **(Eastridge 2012)** In a previous study of MTF deaths, 48.6% (271/558) were categorized as NS and 51.4% (287/558) were PS. Of those who were PS, 80.1% (230/287) were associated with hemorrhage or hemorrhagic shock. **(Eastridge 2011-2)** Injuries categorized as medically NS were physical dismemberment, catastrophic brain injury (brain evisceration, transcranial penetrating brain injury involving deep nuclei or critical vasculature, and brain stem injury), cervical cord transection (above cervical level 3), airway transection within thorax, cardiac injury (>1/2 inch), thoracic aorta injury, pulmonary artery, hepatic avulsion, and catastrophic abdominopelvic injury characterized by lower-extremity amputations with open pelvis and large soft tissue loss/traumatic hemipelvectomy. **(Eastridge 2012)** All other injuries were categorized as medically PS, where care was idealized to immediate access to advanced medical capabilities and robust resources, and do not take into account variables such as offensive versus defensive military actions, tactical combat conditions, the enemy force, logistical constraints, evacuation and transport limitations, and variations in environmental factors.

Civilian Preventable Trauma Death Studies

Dozens of papers examining preventable deaths in civilian trauma have been published. The benefit of having many studies is that there is variation in the specific approaches and questions asked. Some single-center projects have looked at only individual trauma centers, **(Gruen 2006, Teixeira 2007, Stewart 2003)** while other studies have looked at a broader scale of entire states such as Utah. **(Sanddal 2011)** Some examined only in-hospital deaths, others looked at all deaths including those in the prehospital setting. Many studies are U.S. based, while there are also studies from Canada **(Tien 2007)**, the Netherlands **(Zegers 2007)**, and Germany. **(Kleber 2013)** Some examine specific injury patterns and treatment failures of which hemorrhage control of bleeding and airway management seem to be paramount. There have been at least two systematic reviews on the topic. **(Kwon 2014, Settervall 2012)**

The drawback to having so many study designs is that there is wide variation in definitions and criteria for defining "preventable death" in trauma. Most of these civilian studies use some sort of expert panel or board adjudicating the preventability of each death based on their overall opinion, rather than having a list of specific list of explicit criteria as is done in the military. A validated and standard tool for defining and measuring the extent to which a trauma death is preventable would prove most useful in future studies. Although the metrics may be similar, the nuanced differences between military and civilian causes may necessitate slightly different tools.

CURRENT DATA COLLECTION, ANALYSIS, AND INCORPORATION INTO PRACTICE PROCESS IN MILITARY AND CIVILIAN TRAUMA SYSTEMS

Trauma and the Military Health System

The Military Health System (MHS) is a complex system of health care delivery, medical education and training, public health, civilian sector partnerships, research and development, and performance improvement. Data collection and analysis that support performance improvement initiatives drive MHS evidence-based practices into a "learning health system (LHS)" at both the system and patient level. As health care professionals are the backbone of the MHS, data and performance improvement are the backbone of a LHS.

For combat and other overseas contingency operations, military doctrine outlines an integrated system to triage, treat, evacuate, and return the casualty to duty in the most time-efficient manner. The military organizes this system through progressive capabilities referred to as roles of medical care (Role 1, Role 2, Role 3, and Role 4). The system begins with the casualty on the battlefield and ends in a hospital located outside of the combat zone. Specifically, the system begins at the point of injury with prehospital care (e.g. tactical combat casualty care [TCCC]: care under fire, tactical field care, and tactical evacuation care) as provided by first responders (self, buddy, or medic). **(Butler 1996, 2015-2)** This prehospital care is Role 1 medical care and can also include trauma management at an aid station or shock trauma platoon. Role 2 medical care provides limited hospital capability (advanced trauma management, damage control resuscitation, damage control surgery) in combat theaters through small medical treatment facilities and forward surgical teams. Role 3 medical care provides full hospital capability in combat theaters through large medical treatment facilities (e.g. Army combat support hospital, Air Force expeditionary medical support system, Air Force theater hospital, Navy expeditionary medical facility, Navy hospital ship). Role 4 medical care provides full hospital capability outside of combat theaters through large medical treatment facilities located in the continental U.S. (CONUS) and other outside of continental U.S. (OCONUS) safe havens (e.g. Landstuhl Regional Medical Center [LRMC], Germany; Tripler Army Medical Center, Hawaii). **(Cubano 2013)**

The Department of Defense Joint Trauma System

For trauma, the DoD JTS was created to initiate and facilitate a unified trauma LHS with coordination, communication, and process improvement across the spectrum of medical care. For the MHS, the formation of the JTS has been the single greatest advancement in military medicine instituted during the recent conflicts in Afghanistan and Iraq. Initially, a Joint Theater Trauma System (JTTS) was established in Iraq in 2004. This effort occurred following a fact finding

mission in Iraq as directed by the Army Surgeon General in May of 2003. As this trauma system expanded with the establishment of a JTTS in Afghanistan, an umbrella organization called the Joint Trauma System (JTS) was established at the U.S. Army Institute of Surgical Research (USAISR) in San Antonio, Texas in 2006. The JTS was since designated as the DoD Center of Excellence for Trauma on June 19, 2013, and now serves as a coherent, well-organized medical lessons learned center for DoD trauma. The JTS recommends optimal placement of surgical assets, develops triage criteria for casualty evacuation to the appropriate level of care, ensures coordination of efforts and communication within and between treatment facilities, standardizes approaches to treating traumatic injuries, and collects data and maintains a registry (the DoDTR) for near real-time performance improvement, education and training, and refinement of care. The JTS employs a fully-trained support staff inclusive of clinical data abstractors, certified medical coders, and registrars to ensure DoDTR data accuracy. The JTS applies a rigorous quality assurance program to the DoDTR using internal and external consistency checks. Additionally, the JTS and USAISR maintained both performance improvement and research teams in combat theaters in order to ensure near real-time efforts for time-critical issues that were important to the casualties and medical providers in theater. These teams were an essential component of a high functioning trauma system.

The structure of the JTS includes three main branches: Trauma Care Delivery, the DoDTR, and Performance Improvement. The Trauma Care Delivery branch is subdivided into three areas of care: Prehospital, Hospital (Facility), and En Route (Transportation). The JTS CPGs are developed by clinical subject matter experts (SMEs) in response to needs identified in a U.S. Combatant Command (COCOM) area of operations. Topics for CPG development or revision may be presented by any DoD clinician to the JTS Director. The proposed topic should identify a perceived gap in care that would drive change and improve performance. To the greatest extent possible, the JTS CPGs are evidenced-based and result from systematic reviews that consider the quality, quantity, and consistency of the relevant evidence. The evidence is derived from peer-reviewed published literature, from internal JTS analysis of combat casualty data, or as based on evolving experience and expert opinion in theater as dictated by unique environmental and enemy threats imposing novel challenges for medical providers. Where evidence was lacking or unclear, but a CPG was needed, guidelines were developed based on the best available data and subject matter expert consensus. The JTS leadership evaluates proposed CPGs for their relevance to the deployed environment. If a topic is approved, a working group is formed consisting of 10 SMEs and other key clinical leaders, representing all three U.S. military service medical departments. Input from civilian and foreign military SMEs is permissible. Upon approval by the JTS Director, the final CPGs are published on the JTS website.

From conception to publication, these CPGs were usually processed on average within six months as dependent on the complexity and urgency of the CPG. The JTS sends recently published CPGs to COCOM Command Surgeons who share it with their teams and disseminate them to all medical activities within their commands. Individual COCOMs utilize JTS CPGs as is, or modify them as COCOM-specific CPGs. As IOM recommendations for CPG development were released in 2011, **(Graham 2011)** these recommendations were also helpful in guiding future JTS CPG revisions and efforts.

The JTS currently has 44 CPGs. These CPGs are the backbone of the performance improvement program. Routine updates to JTS CPGs occurred every one to two years (a key component suggested by the IOM). If an operational need arose or if new evidence surfaced, the CPGs were modified sooner. The CPGs are currently maintained and archived in a JTS Manager business management tool to protect document integrity and history. The inaugural eight JTS

CPGs were published in December 2004 (Damage Control Resuscitation, Blunt Abdominal Trauma, IntraTheater Transport, Pelvic Fracture, Prevention of Deep Venous Thrombosis, Trauma Airway Management, Urologic Trauma, and Vascular Injury). Among others that have been written since then, the JTS also subsequently wrote a CPG on how to write a CPG in April 2009. The JTS CPGs are freely available online for anyone to access. (http://www.usaisr.amedd.army.mil/10_jts.html)

Monitoring of all CPGs is paramount to the process of performance improvement. The JTS Performance Improvement Branch monitors and measures system-wide CPG adherence through the use of performance improvement indicators which are written into each CPG plan. The performance improvement plan states the intent and minimal performance measures that will be utilized for monitoring. Monitoring of all CPGs, and active participation in military and civilian trauma focused meetings, is essential to ensure CPGs include the latest techniques and innovations. The performance improvement plan states the intent and minimum performance measures to be used for monitoring. Overall mortality rates are improved as a result of CPG-driven performance improvement. Although nominal data have been published in the trauma literature defining the outcomes of evidence-based CPGs, the JTS has conducted analyses that demonstrated the impact of JTS CPGs by showing significant improvements in outcome for burn resuscitation-related mortality (pre-CPG mortality 36%, post-CPG mortality 18%, $p<.05$; CPG compliance 94%), damage control resuscitation mortality (pre-CPG mortality 32%, post-CPG mortality 20%, $p<.05$; CPG compliance 85%), and hypothermia prevention and management after injury (pre-CPG mortality 7%, post-CPG mortality 1%, $p<.05$; CPG compliance 84%) in the context of CPG compliance. **(Eastridge 2009)**

Although initially focused on Role 3 MTF care in combat theaters, the JTS expanded its scope to include all Roles of military trauma care. The current mission of the JTS is to "improve trauma care delivery and patient outcomes across the continuum of care utilizing continuous performance improvement and evidence-based medicine driven by the concurrent collection and analysis of data maintained in the DoDTR." **(USAISR-JTS 2015)** The JTS performs this LHS function through an operational cycle (**Figure 1**): 1. trauma care is delivered and documented in the medical record, 2. data are abstracted and consolidated into the DoDTR (currently the largest repository of combat injury and trauma management information in history), and then 3. data is analyzed for medical situational awareness of the battlefield and for optimal placement of assets within the theater; for performance improvement and to standardize approaches to care and documentation of that care; to retain and convey "operational memory" of common battle injury patterns, especially as personnel and units rotate into and out of the combat zone; for the development and refinement of evidence-based clinical practice guidelines and other knowledge products to include articles published in the medical literature and presentations provided at local, national, and international forums; to address and answer operational and clinically relevant questions; to generate requirements and funding for research and development; to generate requirements and funding for personnel, training, and equipment; to help guide doctrine and policy development; and to routinely discuss and synchronize on-going individual patient care efforts throughout the trauma system continuum and to use these cases to highlight in real-time the individual and system performance improvement achievements and requirements (e.g. JTS weekly worldwide trauma teleconference).

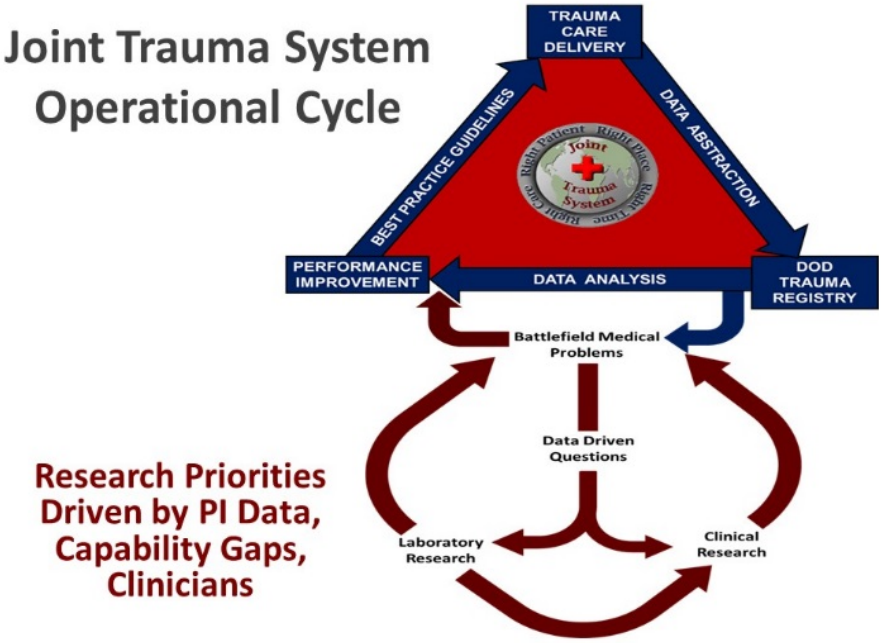

Figure 1 Joint Trauma System (JTS) Operational Cycle and Research Program Philosophy

Recent advances in telemedicine have proven vital to the U.S. military in the management of trauma casualties, particularly in austere environments and combat theaters. Within combat theaters, there are a wide geographical disbursement and physical isolation of healthcare providers, a lack of formal and group continuing education opportunities, and a variable degree of pre-deployment training and education received by these providers, all of which can ultimately result in knowledge deficits and skill attrition. The JTS weekly worldwide trauma teleconference was developed and initiated in February 15, 2006 to overcome these challenges, to build a cohesive trauma system team throughout the continuum, and to mitigate suboptimal differences in outcomes and trauma care delivered to casualties evacuated from the U.S. Central Command (CENTCOM) combat theater of operations (e.g. Afghanistan, Iraq). This teleconference has since expanded to include casualties from other COCOMs (e.g. Africa). This telemedicine conference serves as a LHS communication link and education forum throughout the entire MHS trauma system, from prehospital point of injury and evacuation care through all Roles of DoD medical treatment facility care to Veterans Affairs (VA) and other inpatient and outpatient rehabilitation facility care. This teleconference forum facilitates and propagates performance improvement efforts and initiatives as well as education in casualty care. From February 15, 2006 to October 15, 2015, there have been 485 teleconferences featuring 3,600 case studies. Since March 30, 2012, a total of 2,579 providers have participated with 6,780 continuing education credits awarded. The participants have identified gaps and trends in patient care, and this forum has also served as a conduit for the dissemination of best practices and CPGs, current medical literature, and system advances in trauma care delivery.

The Department of Defense Trauma Registry

In 1999, the U.S. Special Operations Command (USSOCOM) funded efforts to create combat registries to assist with the understanding of combat casualty care much as the Wound Data and Munitions Effectiveness Team (WDMET) database (7989 patients, 1967–1968) did for

our understanding of combat casualty care during the Vietnam War. However, unlike the WDMET database that captured only a sample of the combat injured and provided a retrospective assessment, the DoDTR is continuously updated and offers near real-time assessment and performance improvement opportunities.

The DoDTR (formerly known as the JTTR or Joint Theater Trauma Registry) is a data repository that collects and hosts DoD trauma-related data. The DoDTR is the largest aggregation of military trauma registry data ever assembled, and as of November 6, 2015 this registry contains 130,748 records for 79,697 separate injury casualty events that have been amassed from multiple military and civilian services, treatment facilities, and countries. Data quality within the DoDTR has been under a rigorous quality improvement program since its inception and has developed standard internal and external validations and standard data definitions common to the DoDTR and all its modules. This increases the integrity of the data and decreases error. Registrars maintain a high standard of abstraction, according to their job descriptions and any errors in data are corrected at the source. Data have been used for evidence based CPGs, research initiatives and policy development in order to provide the optimal outcome for the patient.

The DoDTR is optimally designed for performance improvement and provides near real-time collection of data from a multitude of different sources. The DoDTR uses a store and forward capability in combination with a web-based access. Medical coding is optimized through the use of an internally automated coding function. The role, purpose, and design of the DoDTR is distinctly different from that of DoD electronic medical record systems. The DoDTR is an integrated state-of-the-art registry that uses Digital Innovation software. Digital Innovation specializes in the design, development and support of medical registries, and provides routine software updates to the DoDTR so as to maintain up-to-date functions and capabilities. This proprietary commercial-off-the-shelf (COTS) software provided by Digital Innovation and used by the DoDTR has been a relatively easy and more cost effective product to initiate, update, expand, and integrate as compared to government developed independent registries. This software is also used by numerous civilian trauma registries worldwide to include the U.S. National Trauma Data Bank (NTDB), the largest aggregation of civilian trauma registry data ever assembled.

Using standardized data collection business rules and personnel trained and certified in contemporary trauma registry practices (to include Abbreviated Injury Scale [AIS] scoring, International Classification of Diseases-9 [ICD9] scoring, ICD-10 scoring, Registered Health Information Administrator [RHIA] practices, Registered Health Information Technician [RHIT] practices), the DoDTR started collecting and consolidating data in Iraq in 2004, and the initial data collected were primarily from Role 3 medical care facilities. These data were and continue to be manually abstracted from multiple disparate data and information sources to include the Armed Forces Health Longitudinal Technology Application (AHLTA) electronic medical record, the AHLTA-Theater deployed electronic medical record, the AHLTA Clinical Data Repository (CDR), the Composite Health Care System (CHCS) medical informatics system, the Theater Medical Data Store (TMDS) database, the Transportation Command (TRANSCOM) Regulating and Command and Control Evacuation System (TRAC^{2}ES) information system, the Patient Administration Systems and Biostatistics Activity (PASBA) database, Web Interface for Scanned Patient Records (WISPR), the US Army Institute of Surgical Research (USAISR) Medical Record Library, the Essentris Clinical Information System (CIS) electronic medical record, the Defense Enrollment Eligibility Reporting System (DEERS) database, Defense

Manpower Data Center (DMDC) Defense Casualty Analysis System (DCAS), and others. Most recently, the DoDTR has initiated data collection from the Janus Joint Legacy Viewer (JLV).

AHLTA and CHCS are limited access electronic programs that contain outpatient medical records for patients treated at military medical treatment facilities. Information in this program include encounter notes from subspecialists, lab values, radiology reports, lab values, demographic information, soldier readiness, profile histories, and medications. All information in this program undergoes real-time updates. TMDS data sources include AHLTA-Theater and CHCS. TMDS contains demographic information, unit identification, medical information from theater, discharge summaries from theater, and home station facilities for service members. TMDS contains primarily scanned hard copy medical records from Role 1-3, as well as from prehospital and interfacility transport. These records are scanned and loaded by multiple entities to include local Patient Administration (PAD) personnel, deployed JTTS staff, JTS staff, and others. Records include inpatient records, outpatient records, results of laboratory and radiologic tests and procedures, operative notes, blood administration, and TRAC^{2}ES feeds. TRAC^{2}ES provides tracking of Air Force fixed-wing aeromedical evacuation (AE) and patient data from care provided by a Critical Care Air Transport Team (CCATT). TRAC^{2}ES helps deployed medical staff coordinate and monitor patient movement between medical treatment facilities. TRAC^{2}ES interfaces and exports data to TMDS. The TMDS system became more robust after moving from the Joint Patient Tracking Application (JPTA) in 2008. TMDS allows concurrent record abstraction as records are scanned and made accessible. PASBA and WISPR are repositories for scanned hard copy medical records from Role 3 medical treatment facilities located in a combat theater. Records are submitted by PAD personnel, and are then coded, organized and scanned into WISPR. The WISPR system was developed by PASBA to capture and access inpatient records and scanned images of loose paper medical documentation, and contains inpatient and outpatient paper medical documentation from theater not generated by AHLTA. The records contain data from Role 3 facilities as well as any Role 1 prehospital care and transport care or Role 2 facility data available from previous care provided that accompanied the patient to the Role 3 facility. Stand-alone Role 2 facility and Role 3 coalition facility (e.g. the Bastion treatment facility in Afghanistan run by the United Kingdom, and the Kandahar treatment facility in Afghanistan run by Canada) records and data are not included. However, the USAISR Medical Record Library may contain some of these records as scanned and sent to the USAISR by deployed JTTS staff. Essentris CIS is a limited access electronic program that contains inpatient data, medical records, and hospital notes for patients located at each military medical treatment facility. As a patient is admitted to a new facility, a new patient record is started. DEERS contains demographic, occupation, unit, and contact data for DoD beneficiaries. This system is the gold standard for demographic verification of US military personnel. DMDC collects personnel, manpower, financial, and injury information for the DoD. DCAS collects data on military personnel who have been injured or who died in a war or conflict involving the United States. The Janus JLV is a combined effort from the DoD and the Department of Veterans Affairs (VA) for displaying longitudinal health record data from both the DoD Central Data Repository (CDR), which contains information from AHLTA, CHCS, and AHLTA-Theater, as well as the VA Veterans Health Information Systems and Technology Architecture (VistA). The Janus JLV was initially developed from 2001-2003 by Tripler Army Medical Center and the VA Pacific Islands Health Care Systems as a joint DoD-VA venture in order to improve interoperability between the two facilities. Improvement and propagation of Janus JLV have continued through the years.

Acquisition of data into the DoDTR requires a combination of all the above resources. In addition to conducting registry-based performance improvement efforts, records-based research within the military also requires an understanding of how to effectively negotiate these multiple data sources and data acquisition processes. **(Krueger 2013)** Data availability and comprehensiveness can be inconsistent between resources (i.e. scanned record in TMDS vs WISPR) which provide the requirement that each resource be reviewed to ensure a comprehensive review. There exists a continuous struggle with data source providers to ensure DoDTR access to the complete trauma population. However, as the performance improvement benefit of consolidating and analyzing data through a trauma registry became more apparent, it garnered additional support and subsequent resources which permitted expansion of data collection from Afghanistan and other locations, as well as an expansion of the scope of the data to include all Roles of military trauma care.

Role 4 medical care data were integrated into the DoDTR from Landstuhl Regional Medical Center (LRMC), Germany starting in 2007, and then from continental U.S. (CONUS) military hospitals in 2008. Role 2 medical care data were integrated into the DoDTR starting in 2008; however, data collected were intermittent and inconsistent until a 2013 mandate directed these facilities to provide their data. Although casualties benefitted greatly from hospital care influenced by the JTS and DoDTR, still lacking was a comprehensive and integrated system for data collection and analysis to improve the performance of prehospital care, particularly tactical field care and tactical evacuation care. **(Kotwal 2013-1, Kotwal 2013-2, Nohrenberg 2014)**

The task of standardizing prehospital tactical field care documentation tools, and acquiring and consolidating these data into a registry, resulted in the development and institution of novel data collection and consolidation tools **(USAISR-JTS 2015)** that would be acceptable to all military services. Role 1 medical data were integrated into the DoDTR starting in 2013 as data collection tools (TCCC Casualty Card and TCCC After Action Report) were mandated and a JTS PreHospital Trauma Registry (PHTR) was established. These prehospital documentation tools and registry were based on performance improvement efforts and products previously developed by the 75th Ranger Regiment, U.S. Army Special Operations Command, prior to and early in the recent conflicts in Afghanistan and Iraq. **(Kotwal 2004-1, Kotwal 2004-2, Kotwal 2011-1, Kotwal 2011-2)** Both the Ranger and JTS PHTRs and their affiliated prehospital TCCC documentation tools have provided vital data on prehospital care in combat; however, data collection and consolidation remains difficult as leadership mandates and enforcement of these mandates are required to overcome traditional thoughts of this task being too difficult to perform in combat. As of November 6, 2015, only 755 casualties have been entered into the JTS PHTR.

The U.S. Army is doctrinally responsible for prehospital medical evacuation (MEDEVAC), whereas the U.S. Air Force is responsible for the intertheater aeromedical evacuation (AE) of combat casualties. Both of these military services provide intratheater medical transport as dependent on distances and requirements. Casualty evacuation (CASEVAC) involves the unregulated movement of casualties using predesignated or opportune tactical or logistic aircraft and vehicles, which are not staffed with medical personnel nor contain organic medical equipment for en route care unless augmentation is provided during mission planning. As a secondary mission to combat search and rescue (CSAR), the U.S. Air Force can also provide prehospital CASEVAC to supplement the U.S. Army MEDEVAC mission. Data collected on behalf of these missions have proven most beneficial to casualty survival and the validation and optimization of protocols, procedures, and care provided during casualty transport. **(Mabry 2012, Apodaca 2013, Morrison 2013, Ingalls 2014, Kotwal 2015)** Prehospital transport data (Role 1 to Role 2, Role 1 to Role 3) were integrated into the DoDTR in

2014; however, data consolidation initiated formally in 2007 as the U.S. Army Medical Command funded an initiative entitled the "MEDEVAC Project." **(Nohrenberg 2014)** At that time, the JTS was chartered to provide data, analysis, and trends that could be used to guide employment of prehospital evacuation assets and optimize timing of transport and casualty care. Prehospital transport data, intratheater interfacility transport data (Role 2 to Role 3, Role 3 to Role 3), and intertheater interfacility transport data (Role 3 to Role 4, Role 4 to Role 4) are all data that were ultimately integrated into the DoDTR in 2014. A military en route care registry (MERCuRY) has recently been developed so as to capture care provided during all modes of ground, air, and water transport.

As prehospital data can be intertwined with tactics, techniques, and procedures (TTPs), and otherwise sensitive data, some of this data must remain on classified systems and some of this data can be transferred to unclassified systems if it is declassified and transferred appropriately through command agreements and coordinated permissions and procedures. Overall, however, documentation of prehospital trauma care on the battlefield has and continues to be suboptimal. **(Eastridge 2011-1, Kotwal 2013, Sauer 2015, Kotwal 2015)** Although recently developed prehospital documentation tools have aligned data and information to be gathered with up-to-date treatment protocols and practices, and commensurate documentation training has proven adequate, **(McGarry 2015)** medical and non-medical leadership emphasis and community and cultural acceptance is required to increase compliance. **(Kotwal 2011-2, Kotwal 2015)**

Trauma and battlefield care is the quintessential mission of the DoD. **(Mabry 2014)** Although differences reside between the cultures of DoD Services (Army, Air Force, Navy, Marines) and the missions and environments of the U.S. Combatant Commands (COCOMs: Africa, Central, European, Northern, Pacific, Southern, Special Operations), trauma is trauma, and a permanent requirement and authorization through organizational structure (e.g. Modified Table of Organization and Equipment [MTOE], Table of Distribution and Allowances [TDA]) and a foundation of standardized trauma care, trauma care documentation, and trauma registry activities should exist to support performance improvement and a LHS for the entirety of the MHS trauma system (prehospital, hospital, enroute, and rehabilitation care; emergency medical services, trauma surgery, and specialty services; deployed and non-deployed activities; during war and interwar periods) while supplemental guidance and assistance can be provided to scale and account for differences in operational tempo, culture, mission, and environment.

Although a DoD entity, the JTS was established as a non-command and tenant organization of the U.S. Army Institute of Surgical Research (USAISR), which is a subordinate organization under the U.S. Army Medical Research and Materiel Command (MRMC). This position reflects subordinance as an Army program, rather than one that fosters inter-Service collaboration and provides for the needs of all Services within the DoD. Additionally, research does not direct clinical care and performance improvement, rather clinical care and performance improvement processes direct requirements for research. Thus, this hierarchy and structure is suboptimal for guiding research and development efforts, and it limits command and control, streamlined production of doctrine and policy, and the ability to institute authoritative CPGs and trauma care decision-making across DoD Services and U.S. COCOMs. This structure also creates unnecessary levels of bureaucracy that result in delays and a potential for dilution of efforts as trauma initiatives are filtered through individuals who may not be well versed in trauma, and/or not well versed in current recommended strategies for trauma care delivery on the battlefield (prehospital, pre and interfacility transport, and/or hospital). Optimally, the JTS should reside at a higher and more authoritative level in the DoD structure, and empowered with

the ability and resources to better perform its mission of reducing morbidity and mortality from trauma.

As the DoDTR is the main source of trauma data used by other DoD organizations and registries, the DoDTR has the capability of exporting and importing data in a universal format. The DoDTR has provided a number of important analytic products including description of injury severity and mortality and care. Data from the DoDTR have resulted in hundreds of peer-reviewed publications and National and International presentations. In addition to vital relationships with the DoD Services and U.S. COCOMs, the JTS has developed numerous relationships with other DoD and non-DoD organizations in order to inform leaders, share data, and provide comprehensive reports and continuous updates on the status and practices of combat casualty care. The DoDTR has established more than 130 data sharing agreements. Additionally, the JTS has developed partnerships with multiple organizations in order to link DoDTR data to other repositories of trauma-related data. These other organizations include the Armed Forces Medical Examiner System (AFMES), the Joint Trauma Analysis and Prevention of Injuries in Combat (JTAPIC) program, and the Naval Health Research Center (NHRC).

The AFMES provides services that include medical-legal investigations, DoD DNA registry support, aerospace pathology and air mishap investigations, forensic toxicology, and medical mortality surveillance. The AFMES analysis of all active duty military deaths for trends and preventable or modifiable risk factors as proved most beneficial to trauma performance improvement. The AFMES has provided critical data from mortality surveillance and multi-faceted forensic investigations through a team of experts (forensic pathologists, forensic anthropologists, medicolegal death investigators, and forensic photographers). These data as it pertains to combat casualty deaths have contributed significantly to multiple outcome studies to include preventable death studies. **(Holcomb 2007, Kelly 2008, Eastridge 2011-2, Eastridge 2012)** Over the past few years, the JTS and AFMES have also conducted a monthly review of combat trauma deaths in order to mitigate preventable death and provide near real-time performance improvement feedback to medical providers and facilities within the trauma system. The JTAPIC program is a DoD organization with responsibility to collect, integrate, analyze and store operations, intelligence, material, and medical data to inform solutions that prevent or mitigate injury during the full range of military operations. The NHRC is designated as the DoD deployment health research center. Their efforts have optimized the operational health and readiness of the military by conducting research and development to inform DOD policy and practice. Examples of their efforts include the military's largest longitudinal study, the Millennium Cohort Study, the Consortium on the Health and Readiness of Servicewomen (CHARS), and the Joint Medical Planners Toolkit.

The DoDTR, and other partner DoD databases, have accumulated near census and highly detailed data on combat injury and combat casualty care for over a decade. These are invaluable structural resources that should be safeguarded and integrated for use in a strategically coordinated and programmatic effort to assess system performance as based on clinical and patient outcomes. Although the data is robust in quantity, it currently remains under-actualized in quality owing to disunity and underutilization. Unifying these data retrospectively will provide additional actionable information that will inform leaders and benefit both the military and civilian sectors.

Military Trauma and Prehospital Care

Until the advent of Tactical Combat Casualty Care (TCCC) as initially set forth by Frank Butler in 1996, nominal improvement had been made in the prehospital phase of combat casualty care in over 100 years. In summary, TCCC is a set of prehospital trauma care guidelines customized for use on the battlefield. **(Butler 1996)** TCCC began as a Naval Special Warfare Command biomedical research project, and was expanded by USSOCOM and the Uniformed Services University of the Health Sciences (USUHS). **(Butler 2015-2)** TCCC is the direct result of a multi-year comprehensive evidence-based review and analysis that systematically translated tradition-based principles and practices of prehospital trauma care, as provided by such courses as Advanced Trauma Life Support (ATLS) and Prehospital Trauma Life Support (PHTLS), to more effectively meet the requirements of a tactical scenario in combat or a combat-like environment (e.g. active violent incident, active shooter incident, criminal activity, domestic terrorist activity, natural disaster).

The TCCC guidelines are reviewed and updated regularly by the Committee on Tactical Combat Casualty Care (CoTCCC; established in 2001 under USSOCOM, transitioned to the Defense Health Board in 2007, and then to the JTS in 2013 where it currently resides), and detailed support and understanding of these guidelines are published in both civilian and military versions of the Prehospital Trauma Life Support (PHTLS) manual. **(Butler 2010)** As based on input from the JTS, data from the DoDTR, data from the published medical literature, and other sources, the CoTCCC has continuously updated the TCCC guidelines and associated training curriculum to provide current and evidence-based best practices. TCCC guidelines, supporting documents, and training curriculum are structured and available on the JTS, MHS, and National Association of Emergency Medical Technician (NAEMT) websites. **(JTS 2015, MHS 2015, NAEMT-PHTLS 2015)** Updates to TCCC guidelines are also published in the peer-reviewed literature. An official NAEMT and PHTLS-sponsored TCCC course will soon be available in the U.S. and for other countries. This course will be taught by PHTLS and TCCC qualified instructors. The conflicts in Afghanistan and Iraq have seen dramatic changes in prehospital trauma care of combat casualties as a result of TCCC. **(Butler 2012, Butler 2015-2)** Translation of TCCC guidelines to the civilian sector is on-going in many communities in the U.S. and throughout the world. The 2015 U.S. “Stop the Bleed” campaign (http://www.dhs.gov/stopthebleed) is an example of this translation, as it was adopted from the hemorrhage control principles of TCCC.

In addition to providing updates to the TCCC guidelines and training curriculum, the CoTCCC provides up-to-date and prioritized research, development, test, and evaluation (RDT&E) items of interest. Currently, the top five items are: 1) FDA-approved dried plasma product , 2) a Military Use Panel as a shared effort between the DoD and the FDA, 3) electronic methods of capturing prehospital medical care, 4) technologies for prehospital personnel to better judge adequacy of fluid resuscitation, 5) evaluation of the impact of individual and collective TCCC prehospital care interventions on casualty outcomes using DoDTR data. **(Butler 2015-1)**

One of the most notable successes of the TCCC guidelines was the renewed focus on prehospital tourniquet use, as medical and non-medical personnel were previously taught that a tourniquet should be used only as a last resort to control extremity hemorrhage. **(Kragh 2013)** However, prehospital use of tourniquets were subsequently found to be strongly associated with saving lives, **(Kragh 2009)** and did so without limb loss solely due to tourniquets. A study of 2600 combat fatalities incurred during the Vietnam conflict **(Maughon 1970)** and a study of 982

combat fatalities incurred during the early years of conflict in Afghanistan and Iraq **(Kelly 2008)** noted death from extremity hemorrhage was relatively unchanged at 7.4% and 7.8% respectively. However, after global implementation of tourniquet recommendations from TCCC guidelines coupled with the research and development of a modernized and more effective extremity tourniquet, a comprehensive study of 4596 U.S. combat fatalities noted only 2.6% of fatalities resulting from extremity hemorrhage. **(Eastridge 2012)**

Another study was conducted to evaluate battlefield survival in a military unit with first responders, prehospital medical and nonmedical providers, that comprehensively integrated TCCC guidelines and a casualty response system into their training and small unit tactics and also used prehospital data and a PHTR to make near real-time adjustments to TTPs, PPE, and prehospital care. **(Kotwal 2011-1)** Despite higher casualty injury severity, this unit had significantly lower KIA and DOW rates as compared to the larger U.S. military casualty population. Military and civilian prehospital systems that have leadership- and culture-driven integration of medical and nonmedical first responder skills throughout a community, and enact performance improvement of these skills through a registry, may benefit through a reduction in preventable death. A whole-community approach to prehospital care should be considered when attempting to mitigate morbidity and mortality effects of trauma. **(Fisher 2015)** Conversely, comprehensive assessments and observations of prehospital organizations in combat have provided insights into suboptimal trauma system practices that are divergent, outdated, under-resourced, or lack leadership and evidence-based standards and may adversely affect life, limb, and eyesight. **(Kotwal 2013, Sauer 2015)**

Military Trauma and Prehospital Transportation Time

A study of prehospital transport time of combat casualties in Afghanistan noted that prehospital transport time and treatment capability are important factors for casualty survival. **(Kotwal 2015)** A Secretary of Defense mandate to decrease prehospital transport time, and the enforcement of that mandate, translated into practice and compliance, as evidenced by a shift from 24.8% to 75.2% of missions achieving transport in 60 minutes or less. As prehospital helicopter transport time shortened, it afforded critical casualties who would have previously died in the field the opportunity to receive en route and MTF care, while other critical casualties who previously would have died in MTFs were also afforded care earlier. Despite higher casualty injury severity, as transport time decreased and capabilities increased, casualties who would previously have been categorized as KIA survived or survived long enough that they shifted to be categorized as DOW. Additionally, casualties who would previously have been categorized as DOW were also surviving.

If the key to trauma care resides in decreasing time to a required capability, with the requirement dictated by the injury, and the capability effectively performed in a timely fashion to optimize outcome; **(Clarke 2012, Mabry 2012, Kotwal 2015)** and if the key to reducing battlefield mortality resides in focusing on prevalent causes of death; and if hemorrhage is currently the prevailing cause of combat death; **(Eastridge 2011-2, Eastridge 2012)** then ultimately reducing time to successful implementation of pre-surgical hemorrhage control, surgical hemorrhage control, and blood product replacement is vital to battlefield care.

In addition to optimizing medical evacuation platforms and medical and flight crew performance and response, an increase in the number of evacuation platforms, surgical facilities, or both (with associated personnel, logistical support, and monetary cost) may be required to achieve transport times commensurate to the needs of a military population at risk. Failure to

achieve balance between supply and demand may push systems to achieve mandated times with inadvertent cost resulting from evacuation crew error, evacuation platform materiel failure, environmental conditions, and hostile fire.

Military Health System and Characteristics of a Continuously Learning Health System

The Institute of Medicine (IOM) has categorized the characteristics of a continuously learning health system into four major groups: (1) science and informatics (real-time access to knowledge, digital capture of the care experience); (2) patient-clinician partnerships (engaged and empowered patients); (3) incentives (aligned for value, full transparency); and (4) continuous learning culture (leadership-instilled culture of learning, supportive system competencies) (IOM, 2013). Benefits resulting from these characteristics include improvement of clinical decision making, improvement of health care safety and quality, real-time generation and application of knowledge for health care improvement, health care anchored in patient needs, teamwork and collaboration in support of continuous learning as a core aim, systems analysis and information development, and the creation of feedback loops for system and performance improvement. **Table 2** denotes to what degree these characteristics have been integrated into current trauma care systems, with specific comparison of the military versus civilian systems. Although pockets of excellence can be identified, both systems have characteristics that can be improved and barriers to be removed, particularly in the realm of decision making and leadership. Notable for both systems is that on each characteristic of a learning health system, no entity of care is currently functional and without barriers (“1A”); all have a decision-making barrier (“D”); 56 percent have a confidentiality barrier (“C”); and 55 percent have a budgetary barrier (“B”).

Table 2. Characteristics of a Continuously Learning Health Care System Integrated into Military vs. Civilian Trauma Systems

Status:
1 - Functional
2 - Progressing
3 - No Progress

Barriers to Implementation:
A - Absent (No Barriers)
B - Budgetary (Lack of Priority and/or Financial Restraints)
C - Confidentiality (Policy, Regulations, and Concerns for Patient Privacy, and/or Operational Security)
D - Decision Making (Lack of Leadership, Decision Making, Mandate, Policy, and/or Culture)

			Prehospital	**En Route 1**	**Hospital (Initial)**	**En Route 2**	**Hospital (Intermediate)**	**En Route 3 and En Route 4**	**Hospital (Final)**	**Post-Discharge**
Military			Role 1, Non-Medic First Responder, Medic	PH-Hosp, CASEVAC, MEDEVAC, Medic	Role 2, FST, Small	Hosp-Hosp, Intratheater, (medic and nurse)	Role 3, Area Support, Large	Hosp-Hosp, Role 3 to 4, Role 4 to 4, Intertheater, AE, CCATT (ICU physician, ICU nurse, Respiratory Therapist)	Role 4, Regional, Large, Referral Center	VA, Rehab. Facility (Inpatient, Outpatient)
Civilian			Layperson	First Responder EMT, Paramedic	Lower Level, Non-Trauma Center	NA	NA	Hosp-Hosp (paramedic and/or nurse)	Trauma Referral Center	Inpatient and Outpatient Rehab.
Science and Informatics	***Real-time access to knowledge***	MIL	2BCD	2BCD	2BD	2BD	1D	1D	1D	2CD
		CIV	3CD	2CD	2BCD	NA	NA	1BD	1BD	2D
	Digital capture of the care experience	MIL	3BCD	3BCD	3BCD	3BCD	2D	2D	1D	3CD
		CIV	3BCD	1D	2BD	NA	NA	2D	2D	2BD
Patient-Clinician Partnerships	***Engaged, empowered patients***	MIL	3BD	3BCD	3CD	3CD	1CD	1CD	1CD	2CD
		CIV	3D	2D	2D	NA	NA	2D	2D	2D
Incentives	***Incentives aligned for value***	MIL	2CD	2CD	2CD	2CD	1D	1D	1D	3CD
		CIV	3D	1D	2BD	NA	NA	1D	1D	2CD
	Full transparency	MIL	3BCD	3BCD	3BCD	3BCD	3BCD	3BCD	3BCD	3BCD
		CIV	3CD	2CD	1BD	NA	NA	2BD	2BD	2CD

Continuous Learning Culture	***Leadership instilled culture of learning***	MIL	2BCD	2BCD	2BCD	2BCD	2BD	2BD	2BD	3BCD
		CIV	3BCD	2BCD	2BCD	NA	NA	2BCD	1CD	2BCD
	Supportive system competencies	MIL	3BCD	3BCD	3BCD	3BCD	2BCD	2BCD	2BCD	3BCD
		CIV	2BD	2BD	2BD	NA	NA	2BD	2D	2BD

Abbreviations: Aeromedical Evacuation, AE; Casualty Evacuation, CASEVAC; Medical Evacuation, MEDEVAC; Critical Care Air Transport Team, CCATT; Emergency Medical Technician, EMT; Forward Surgical Team, FST; Military, MIL; Civilian, CIV; Veterans Affairs, VA; Not Applicable, NA.

Notes: Notable for both military and civilian systems is that no one entity of care and matched characteristic is currently functional and without barriers (“1A”), 100% have a decision-making barrier (“D”), 56% have a confidentiality barrier (“C”), and 55% have a budgetary barrier (“B”).

In the area of **science and informatics,** the barrier is not technology. The advanced interconnectivity of computers and mobile devices (e.g., iPhones) is remarkable. In fact, many people have better, more seamless transitions (i.e., cloud-based sharing of files, contacts, photos, etc.) in their personal lives than in the health care information technology world. Robust systems exist for both real-time data access and digital capture of health care, which have been implemented successfully by some. However, the use of technology has yet to be maximized and globally integrated into trauma system practices.

Specifically, on the civilian side, the National Emergency Medical Services Information System (NEMSIS) project ensures the standardization and exportability of out-of-hospital patient care information among all health care systems in U.S. states. Nevertheless, existing health information exchanges have few federal or state incentives to integrate emergency medical services (EMS) data into electronic health records (EHRs). Some EMS agencies have Global Positioning System (GPS)-enabled tablet computers in the back of ambulances capturing time-stamped vital signs and procedures. However, when EMS providers arrive at a trauma center, they cannot download the computer-generated documentation directly into the hospital electronic medical record or trauma registry. They may need to print their data to be scanned into a nonsearchable medical record days later, only to be reabstracted by hand by a trauma registrar, losing data fidelity and not giving the trauma team immediate access to the information. Similarly, the nearly ubiquitous use of the National Trauma Data Standard (NTDS) in acute care hospital-based trauma registries and adoption of Trauma Quality Improvement Program (TQIP) performance measures and monitoring greatly enhance standardization of care decisions and benchmarking of performance metrics. However, the interoperability of these products with other phases of care and health care exchanges remains limited.

Some electronic medical records allow storage of images (i.e., photographs of traumatic wounds, operative procedures). Yet many have not been enabled because of lack of leadership understanding of the importance of these visual data and greater priority of concerns about possible regulatory and Health Insurance Portability and Accountability Act (HIPAA) violations. Privacy concerns have been raised, especially as leaked photos of high-profile cases have appeared on social media sites. Yet the informal workarounds used (e.g., residents taking photos and text messaging or emailing attending physicians) likely put confidentiality more at risk than if leaders would acknowledge that this occurs and enable a more controlled approach to optimizing image sharing. Some studies of specific integrated computerized clinical decision support tools have shown that they dramatically improve care, but they have been used only sporadically.

On the military side, there are real concerns about operational security as technology can provide friendly force location, troop composition, and other detailed information to enemy forces or others who would do harm. Although secure systems have been developed and are in use, interfacing classified and unclassified data systems requires leaders who realize that performance improvement must be accomplished regardless of the classification and where data reside. Unclassified data residing on classified systems can be transferred to unclassified systems if appropriate measures and approval are obtained. Although classified data residing on classified systems cannot be transferred to unclassified systems, unclassified data on unclassified systems can be transferred to classified systems for integrated analysis with classified data. Although active mission details and information on trauma training programs (TTPs) and personal protective equipment (PPE) must be safeguarded so as not to provide enemy forces with friendly force vulnerabilities, these data can still be analyzed and published on classified systems in near

real time for performance improvement and to inform leaders. Additionally, when some unclassified data are being aggregated, these data can become classified and should then be transferred to classified systems.

Patient–clinician partnerships are critical to ensure that care remains focused on the factors that patients value. The concept of patient-centered care is not new, but it is receiving more attention, especially with the creation of the Patient-Centered Outcomes Research Institute (PCORI). In some areas of trauma care, patients are routinely and heavily engaged and drive decision making. For example, patient advocacy groups have been instrumental in improving long-term care for trauma patients with spinal cord injury, traumatic brain injury, and amputations. These groups, many of which focus on military injuries, raise awareness and funds while helping give patients a voice to let their preferences be known. Collaborative projects between researchers and patient stakeholders provide usable data, allowing patients to make informed decisions about their medical care. For example, amputation decisions may be informed by prospective observational studies that have shown differences in long-term functional outcomes when comparing amputation versus limb salvage for patients with severe lower extremity trauma in both the civilian (Bosse et al., 2002) and military (Doukas et al., 2013) settings. Yet in other areas, patients are less empowered to change trauma care delivery, and decisions are made with little to no patient input.

The major barrier to improved patient-centered care falls under the category of decision making. The issue is not one of mandate or policy; it is primarily a lack of leadership from medical professionals, who are often hesitant to change culture. Newer ideas, such as including family members in multidisciplinary rounds and engaging them to help with care (e.g., range-of-motion exercises, bathing) of intensive care unit (ICU) patients, are still uncomfortable for some physicians and nurses. However, early feedback suggests that families and patients end up with a better experience overall as a result of these practices and may have improved outcomes (Wyskiel et al., 2015a,b).

Incentives, especially those that are financial, are often not aligned to encourage continuous improvement within a learning health system. Although some changes in the forms of value-based purchasing and pay for performance are slowly occurring, the classic fee-for-service model is still the norm in much of the private sector. A major difference between trauma care in the civilian and military sectors is that the military basically has a single-payer system, covering all aspects of care for its covered population. This should, in theory, help align financial incentives across the continuum of care. However, an extremely large budget coupled with little financial accountability may also drive military health care spending, rather than pushing it to reduce waste and reward high-value care. Accordingly, barriers to progress in this area are somewhat financial, but are also driven by culture and lack of leadership. The aim of the Choosing Wisely campaign is to cut back on unnecessary medical testing and procedures (Morden et al., 2014), but the campaign's reception has been somewhat lukewarm as individual physicians often do not want their practice of the art of medicine to be dictated to them from external sources.

In a **continuous learning culture,** active monitoring of the quality and safety of health care is a major focus. The importance of data use in quality improvement work is discussed later, but must be mentioned here as there are numerous barriers to allowing this to occur in a useful manner. From a budgetary standpoint, financial incentives in this regard have been sorely lacking. Most hospitals expend considerably more resources on and have many more data analysts assigned to financial issues (e.g., supply chain, staffing) versus quality-of-care

improvement initiatives, indicating their true prioritization. Some issues of confidentiality exist, especially when attempting to learn from individual patient harm. On the civilian side, hospital lawyers and risk management departments frequently fear financial and/or reputational losses and therefore do not allow examples of harm to be shared so others can learn and prevent errors from occurring again. To some degree, the military has been effective in overcoming this barrier by establishing and maintaining a Joint Trauma System (JTS) weekly worldwide trauma teleconference that connects the entire continuum of the trauma system in order to critically review trauma care delivery for best practices as well as for performance improvement opportunities.

The most critical and ubiquitous barrier to a learning health system in both the military and civilian sectors relates to decision-making. The trauma systems of both sectors lack the leadership necessary to promote and maximize learning from failures and mistakes, and push for changes in practice in order to prevent recurrences of errors. In the military, leaders are often comfortable promoting good news stories such as "highest combat casualty survival rate in history;" however, these same leaders are often reluctant to take it to the next level and be relentlessly dissatisfied with any degree of preventable morbidity and mortality. Additionally, as medical leaders do not own prehospital assets, and as nonmedical leaders who own prehospital assets are not held accountable for medical efforts, there is no true ownership of prehospital preventable morbidity and mortality, which is where most combat deaths occur (Butler et al., 2015; Eastridge et al., 2012; Kotwal et al., 2013; Mabry, 2015). There remains a pervasive cultural barrier to learning from mistakes in civilian medicine. In particular, a clearly defined hierarchy both within physician ranks (student, intern, resident, fellow, attending) and among professionals (physicians, physician assistants, nurses, medics) limits safety improvement in real time, as not all health care professionals feel comfortable speaking up, even when egregious errors are about to be made. The military hierarchy of rank exacerbates and complicates this concern.

Although the military and civilian levels of care do not always have direct analogues, the overall general structure of prehospital, in-hospital, and postdischarge care is similar. The nuances remain different at every level, but where similarities exist, there can be opportunities to share best practices and learn from one another. One major difference is the proportion of patients who undergo interhospital transfer. In combat theaters, the vast majority of injured military patients do not remain at the initial treating facility. Most undergo at least one and more frequently two interhospital transfers, often across thousands of miles and multiple continents. To achieve this medical transportation, the military has multiple modes of transport as well as various types of medical providers, depending on where the evacuation is occurring. In the prehospital realm of a combat zone, where personnel and transportation assets are subject to hazardous conditions, medical capabilities for casualty evacuation (CASEVAC) and medical evacuation (MEDEVAC) have traditionally been more limited. However, recent data from the Afghanistan conflict have shown that increased medical capabilities on prehospital transport platforms, similar to the practice in the civilian sector, can improve morbidity and mortality on the battlefield (Kotwal et al., 2016; Mabry et al., 2012; Morrison et al., 2013). Rapid interfacility aeromedical transport out of a combat zone, with robust critical care air transport team (CCATT) en route capability (ICU physician, ICU nurse, and respiratory therapist), has proven effective (Ingalls et al., 2014). Additionally, interfacility transport between Role 4 hospitals (Outside Contiguous United States [OCONUS] to Contiguous United States [CONUS] or CONUS to CONUS) has proven beneficial from the standpoint of patient-clinician partnerships as family

members have been afforded the opportunity to travel as attendants with their injured family members. **Appendix III** provides an example case of an injured military service member to illustrate the multiple transports as well as highlight the opportunity for better data use along the continuum of care.

In the civilian sector, the majority of injured patients remain at the first hospital to which they arrive. Some patients are transferred from the initial treating center for medical necessity (i.e., higher level of care and/or specialized services) or for social reasons to be closer to home/family if they were injured in a different state or region.

Differences also exist between the military and civilian trauma care systems in most other categories. One key difference is in the immediate first response to an injured patient. In the military setting, all personnel have received some degree of basic trauma training and tools (e.g., tourniquets, pressure dressings) to begin self- or buddy care. In the civilian sector, a minority of the public truly understand initial trauma care, and rarely are they provided such tools. Emerging from the military's tactical combat casualty care (TCCC) guidelines, the 2015 "Stop the Bleed" campaign (http://www.dhs.gov/stopthebleed) recently began to address this concern. For trained prehospital providers, the military education system is focused primarily on traumatic injury care, environmental injury prevention and care, and care for common minor illnesses. In the civilian realm, emergency medical technicians (EMTs) and paramedics receive broader training that encompasses all aspects of care (e.g., cardiac arrest, obstetrical emergencies). While the equipment, personnel, staffing, and medical care available at the final destination hospital are comparable, there are likely dramatic differences in resources between military and civilian initial hospital care. A basic non-trauma center emergency department may likely have more physical capabilities (e.g., x-ray, computerized tomography (CT) scan) than a forward surgical team operating in a tent; however, it may lack immediate surgical response training as provided by the military. Arriving at a forward surgical team (FST) in a combat zone versus a small rural non-trauma hospital may prove advantageous for a casualty if the FST has been seeing patients routinely; however, this may not be the case if it has been a while since the FST has seen and treated a casualty.

While **Table 2** illustrates barriers with respect to characteristics of a continuously learning health system for both the military and civilian trauma systems, **Table 3** highlights specific military trauma system gaps or barriers in data collection, distribution, and use whose resolution could improve trauma care and patient outcomes.

Table 3 Specific military trauma system gaps or barriers in military trauma data collection, distribution, and use.

1. Global mission with challenges including "tyranny of distance" resulting in limited or isolated facilities, long transports, and trauma care delivery and data collection in austere, hostile, and under-resourced environments.
2. DoD and Theater trauma system and registry is not institutionalized. There is no permanent requirement and/or authorization document (TDA, MTOE). No permanent personnel and/or resources.
3. Clinical practice guidelines must be tailored to mission, enemy actions and tactics, as well as to multiple environments at sea, on land, and in the air.
4. Suboptimal data collection at prehospital Role 1: battalion aid stations, tactical combat casualty care (care under fire, tactical field care, tactical evacuation)
5. Suboptimal data collection at Role 2: forward surgical teams and intratheater interfacility transport.

6. Suboptimal combat prehospital structure. No overarching ownership or commander for prehospital medicine. Lack of Prehospital Experts and EMS directors trained and assigned to tactical (prehospital) combat units, thus TCCC is inconsistently implemented as concepts are outside of comfort zone and training provided through civilian-based residency programs.
7. "Responsibility for battlefield care delivery is distributed to the point where seemingly no one 'owns' it. Unity of command is not established and thus no single senior military medical leader, directorate, division or command is uniquely focused on battlefield care, the quintessential mission of military medicine." **(Mabry 2014)** Example of the adage, "when everyone is responsible, no one is responsible."
8. Funding to study military trauma care is limited. Non-defense related medical research has received more funding in the DoD over the past decade than defense related medical research. Of defense related medical research, research and development efforts are primarily focused on material advances. Additionally, medical combat development efforts are focused on rearranging existing paradigms for doctrine, manpower, and equipment; however, this is in spite of the fact that training, leadership, and organization efforts have made the most significant documented improvements in survival. **(Kotwal 2013, Mabry 2014)**
9. Interwar mission and relevance of trauma care remains underappreciated. Trauma is the leading cause of death, even during times of relative peace. Trauma continues to occur from military aircraft and vehicle crashes, training for combat, and static-line and free fall parachute incidents.
10. Lack of JTS, JTAPIC, AFMES, Safety Center, VA data integration and access.
11. "Military Medicine" needs to be further developed and refined as a specialty or fellowship, with associated education and training goals and metrics.

U.S. CIVILIAN TRAUMA SYSTEM AND DATA COLLECTION

Civilian Prehospital Data Collection

Prior to the year 2000, little had been accomplished to standardize the collection of clinical information collected by Emergency Medical Professionals responding to requests for emergency care or transporting patients between facilities. The Office of EMS, within the National Highway Traffic Safety Administration (OEMS-NHTSA), had supported the development of the Uniform Prehospital Dataset **(NHTSA 1994)**, which served as a guide for the development of agency-level patient care reporting systems, but was not intended to bring all national EMS data collection into conformance. An additional important publication initiated by OEMS-NHTSA was the "EMS Agenda for the Future" **(NHTSA 1996)**. This document highlighted five essential recommendations needed to ensure interoperability and collaboration among civilian EMS information systems:

1. EMS must adopt a uniform set of data elements and definitions to facilitate multi-system evaluations and collaborative research.
2. EMS must develop mechanisms to generate and transmit data that are valid, reliable, and accurate.
3. EMS must develop and refine information systems that describe the entire EMS event so that patient outcomes and cost-effectiveness issues can be determined.
4. EMS should collaborate with other health care providers and community resources to develop integrated information systems.

5. EMS information system users must provide feedback to those who generate data in the form of research results, quality improvement programs, and evaluations

The National Emergency Medical Services Information System

These recommendations would soon be realized with the initiation of the National Emergency Medical Services Information System (NEMSIS) project in 2001. The NEMSIS project developed a standard data dictionary designed to characterize: EMS system responsiveness; patient characteristics and detailed attributes of the patient's underlying illness or injury; medication/procedure use and effectiveness; and protocol adherence. Other sundry items available include EMS agency characteristics, patient complaint reported to 9-1-1 call centers, delays experienced in the EMS response, identification of mass casualty events, and patient disposition decisions, etc. These data elements are endorsed by state EMS authorities in 56 states and territories. Along with a data dictionary, a standard non-proprietary structure for data transmission was developed, which is perfectly harmonized with the elements contained in the data dictionary. The data dictionary and transmission structure contain a near complete compilation of all applicable EMS elements, from which each EMS agency may choose elements to collect. Nevertheless, a local agency's choice of elements must include those elements mandated/requested by states and those required for population of a the National EMS Registry. Using this approach, each local EMS agency may tailor their data collection approach, but ensure standardization with state and national EMS registries.

Commercially available software used by EMS agencies to collect patient care information is approved as "compliant" to the NEMSIS data elements and transmission standard by the NEMSIS Technical Assistance Center (TAC). A list of compliant software can be found on the NEMSIS website **(NEMSIS 2015-2)**. Software is also evaluated to be compliant with other attributes of the NEMSIS process, including use of national "business rules" to enhance data quality and application of a standard web services program to provide near real time data capture and export to state and national repositories.

Civilian EMS agencies completing patient care reports, at the time of record completion, will be prompted to correct errors identified by the standard business rules. Once errors are corrected, the electronic record is closed and immediately exported to the state repository and the subset of national elements are parsed and then sent from the state repository to the national EMS registry. Currently, the average time from record closure by the EMS provider to arrival of the record at the National EMS registry is 6 minutes.

Figure 2 illustrates how a standard XML format is utilized to not only export patient care reports to state and national repositories, but also provides a standard mechanism for additional information (e.g., medical device data) to import into the patient care report. More importantly for our purposes, EMS data can also be exported to other related registries or data collection systems using the standard XML. **Figure 2** also illustrates an existing "harmonization" that exists between the NEMSIS compliant dataset structure and hospital trauma registry datasets that are compliant with the American College of Surgeons (ACS) National Trauma Data Bank (NTDB) standard.

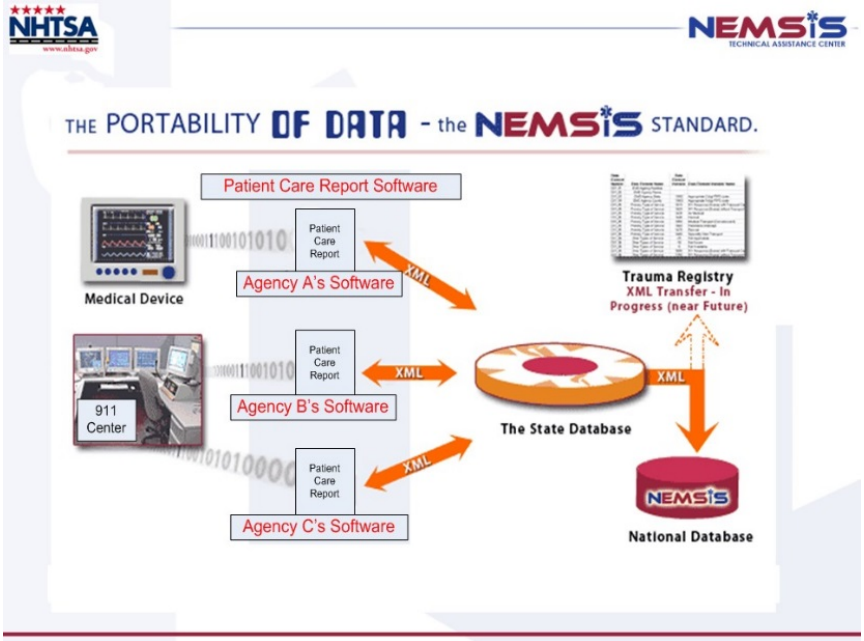

Figure 2 The Portability of Data within the Pre-hospital Information System

Collaborating with individuals associated with the ACS NTDB, prehospital elements contained within NEMSIS that are similar to those contained in the NTDB standard for hospital trauma registries were “harmonized”; meaning common elements in both datasets (and their export structures) were redefined to be exactly the same. Thus, data can be exchanged with no additional transformations. An example of this process is present in the state of Kansas. The Kansas state database server for hospital trauma registries (i.e., KDHE) is connected to the state database server for EMS data (i.e., KEMSIS, see **Figure 3**). When Kansas EMS providers treat an injured patient, they record in the appropriate NEMSIS element the hospital to which they will be transporting the patient. Trauma registrars within that hospital can search the KEMSIS database the EMS record for the arriving patient. Once identified (i.e., linked), the prehospital elements contained within the hospital trauma registry auto-populate. Data exchange is “permitted” based upon the concept that pre-hospital emergency care is directly associated with the health event leading to the patient's hospitalization.

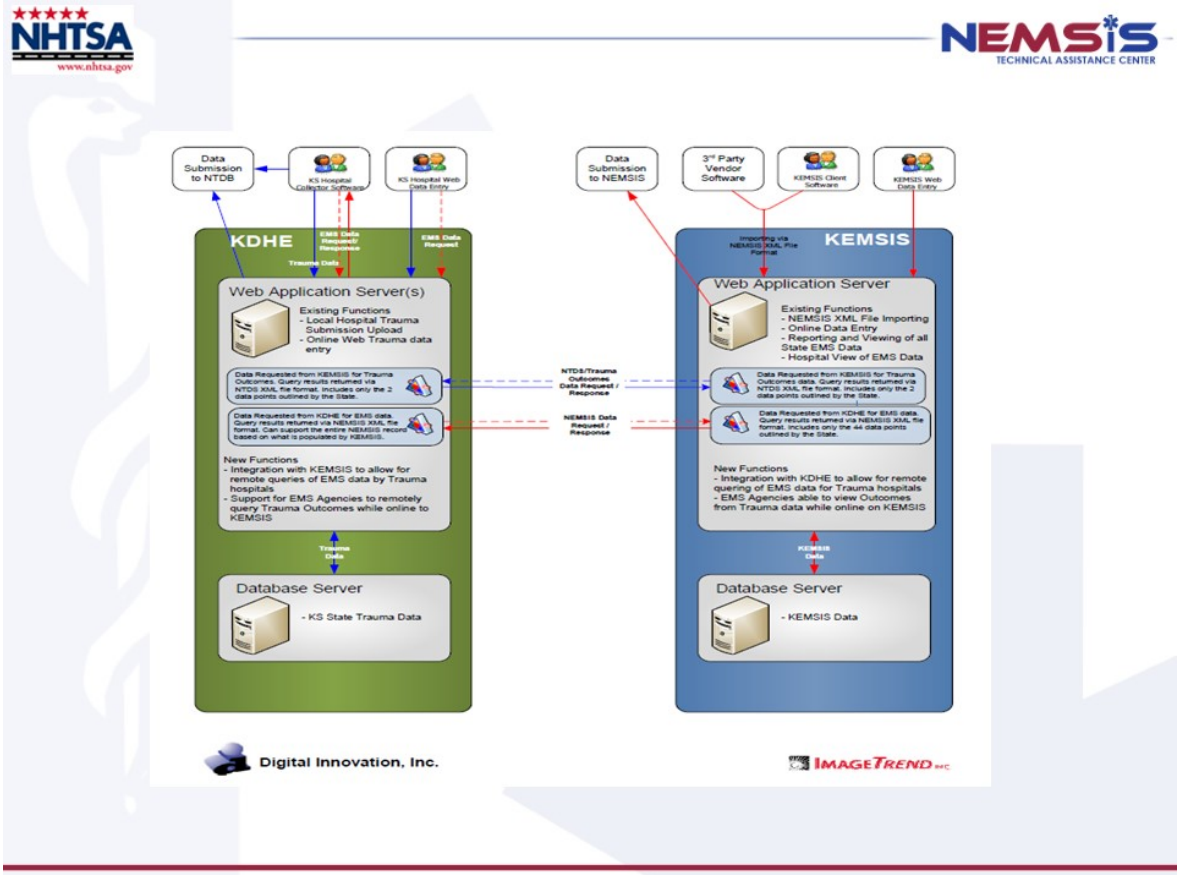

Figure 3 Data Interoperability between Kansas EMS and Trauma Registries

EMS Data Privacy Concerns

The exchange of EMS data from local EMS agencies, to state repositories, to the National EMS Registry is possible because essentially no identifying information (as defined by HIPAA) is exchanged. That is, patient care information identifying an individual patient is rarely submitted to a state repository, unless allowed by state rule, and is never submitted to the National EMS Registry. This policy made it possible for Data Use Agreements to be initiated with each state, formalizing the process of data exchange. At the national level, the consequences of this approach are that multiple records over time for the same patient cannot be associated and the lack of geographic measures, such as Patient Home Address, makes it impossible to conduct geographic analyses. Also, linkage with independent registries is limited to approaches such as those outlined in the State of Kansas example.

The National EMS Registry

For 2014, the National EMS Registry contains 25,835,729 EMS activations submitted by 9,693 EMS agencies serving 48 states and territories. Data submitted by agencies primarily characterize EMS ground activations, based on 9-1-1 requests for emergency care, although several states also submit interfacility/acute care transports and/or air medical transports.

The registry inherits the individual data deficiencies originating from the contributing EMS agencies. Data files received at the NEMSIS TAC from contributing states are checked for proper structure and completeness, and over 300 logical consistency checks are applied. Any data files not passing NEMSIS validation and the data cleaning processes are rejected or flagged based on the seriousness of the discovered errors.

Submitted files not meeting data structure rules (e.g., a code value not found in the NEMSIS standard) are perfunctorily rejected. For files passing structure validation, a data quality profile is generated for each submitted file allowing state EMS officials the opportunity to review the quality of submitted data, correct errors, and resubmit their data if they wish. If the state re-submits a corrected file, the previous data file is replaced; otherwise, the original files that were flagged remain in the database. Any data errors or inconsistencies not identified/corrected through this process are allowed into the registry.

Currently, the National EMS Registry is made publically available with three consecutive years of data (over 53 million EMS records). As of 2015, local and State EMS professionals use NEMSIS data frequently to conduct epidemiological investigations and to develop performance metrics. A peer-reviewed research paper based upon NEMSIS data is published, on average, every five days.

Important Future Data Sources

An additional source of injury data that may soon be available to civilian trauma systems is Advanced Automatic Collision Notification (AACN) information. In essence, AACN data are vehicle telemetry information collected at the time of a vehicle crash. A primary purpose of AACN is to provide “advanced” telemetry that may inform emergency medical responders regarding the location and characteristics of a vehicle crash, and importantly, the possible severity of resulting injuries. AACN systems capture exact data on factors such as speed, crash force, airbag deployment and seatbelt use. Investigators have utilized these data points to define probable injury severity metrics **(Kononen 2011)**. Some AACN systems currently available in newer model vehicles can automatically call 911 to summon EMS personnel in the event the vehicle occupants are incapacitated. Research has shown the ability of AACN metrics to predict occupant injury in both adults **(Augenstein 2003)** and children. **(Nance 2006)** The current NEMSIS standard includes 15 common AACN elements defined in the Vehicular Emergency Data Set (VEDS), developed by the ComCARE Alliance as a national standard for AACN systems. These data elements could be included in an electronic transfer of patient data to awaiting emergency departments. Authors have called for the “potential use of advanced automatic collision notification in planning an EMS response.” **(Ayoung-Chee 2013)**

Aggregated Civilian Inpatient Trauma Registry Data: The National Trauma Data Bank (NTDB)

Due to the sustained efforts of the American College of Surgeons Committee on Trauma (ACS-COT), the National Trauma Data Bank (NTDB), initiated in 1989, became and has remained the primary source of aggregated trauma registry data in the U.S. The NTDB currently collects patient-level injury event, injury severity and patient care measures characterizing over 800,000 severely injured patients each year. Every year, approximately 750 hospitals submit standardized trauma registry data, based upon a comprehensive dictionary and set of inclusion criteria, to the NTDB through a VPN portal that evaluates the quality of the data submitted. A

description of the inclusion criteria and data dictionary can be found at: http://www.ntdsdictionary.org/.

In 2009, the ACS-COT implemented that National Trauma Data Standard (NTDS) which standardized hospital trauma data collection and data exchange with the NTDB and ensured data harmonization with prehospital elements in common with NEMSIS. Harmonization between the NTDS and NEMSIS remains seamless through continued communication between the two standards as revisions are made. Implementation of the NTDS greatly improved the data quality contained in the NTDB, with has resulted in a sharp increase in the volume peer-reviewed publications written annually using the NTDB. Recently, research using linked NTDB/National EMS Registry data has been presented at scientific meetings and prepared for publication. **(Bryne 2015)**

Despite this incredibly valuable source and volume of trauma care information, gaps in our understanding remain. The NTDB includes data characterizing the acute phase of care for trauma patients. No additional data collection for unplanned readmissions, delayed complications or, planned readmissions (i.e. orthopedic surgery, colostomy takedown, ventral hernia repair, etc.) is attempted. NTDB data cannot be linked to outpatient clinic visits, rehab center admission data, or Veterans Affairs (VA) data. The NTDB does include information regarding the transfer status for individual patients, but the collected data does not identify to which hospital a patient was admitted, and if applicable, to which hospital the patient was transferred.

Other Sources of Injury Data: Coroner / Medical Examiner

While the NEMSIS and NTDB are excellent aggregated data on the prehospital and inhospital phases of trauma, there are other possible data sources that can be used to complete the full spectrum of information regarding the burden of injury and trauma care. Ideally, every phase of trauma care should have its data available for scrutiny and rigorous study. It has been known for decades that many injured patients die immediately after injury, never receiving any medical care. **(Trunkey 1983)** The data for this group of patients not treated by EMS or transported to a hospital is often not examined very closely. The routine use of traditional autopsy by civilian coroners and/or medical examiners is relatively uncommon, unless there is a legal driver for it to be performed (i.e. homicide, vehicular death). Computed tomography (CT) autopsy has been studied for over 20 years, but has only been used sparsely in the civilian sector. **(Donchin 1994)** The military system is quite different in that all service members who are categorized as KIA or DOW are examined in a thorough attempt to glean as much information from their injuries in an effort to impact change and improve performance. **(Champion 2010)** The use of CT autopsy has been growing exponentially in the military. **(Grady 2009)** Although autopsy clearly has no benefit to the individual patient, there may be societal benefit if the findings lead to improved safety devices. For example, military autopsy data has helped to drive improvements in personal protective equipment (PPE). Similarly, civilian autopsy data may lead to improvements in safety devices such as seat belts, air bags, helmets, etc. It also may help lead to changes in future medical therapies if autopsies are performed on patients who received some degree of medical care.

To obtain a true and complete picture of trauma mortality, information from all deaths in a trauma system must be collected. Examining only a single data source will lead to underestimation of the burden of injury. Estimates of injury mortality are significantly higher when using multiple independent databases. **(Mann 2005)** Differential transport criteria, protocols, and regulations can lead to different groups of patients arriving at trauma centers who

are moribund and unsalvageable. This issue is important for trauma benchmarking as there is likely differential transport of moribund or already dead patients to trauma centers based on local EMS culture and/or policy. **(Efron 2006)** It is also critically important to attempt to capture deaths that occur after initial hospitalization. Inhospital mortality rates are well known to be incomplete measures of death after injury. **(Mullins 1998, Davidson 2011)**

Learning from Mass Casualty / Multiple Casualty Event Data

The importance of collecting data on patients injured by both natural and manmade disasters cannot be overlooked. Although relatively rare, these events give fertile ground and are a data rich environment for a learning healthcare system. Unfortunately, the adage that "those who do not study history are doomed to repeat it" applies perfectly to this type of setting. When numerous casualties need care immediately and overwhelm the available resources then a mass casualty event is underway. As we can expect this type of disaster to continue to occur, it is imperative to prepare as best we can using all available data. Descriptions of wounding patterns, interventions, and outcomes caused by large scale bombings (i.e. Beirut marine base) lead to new knowledge. According to to Dr. Rick Frykberg, "critical analysis of disasters such as this can contribute to improvements in preparation and casualty care in the event of future disasters." **(Frykberg 1989)**

Similar data should be considered for all types of disasters. These can include natural disasters (i.e. hurricanes, tornado, earthquake, flood), unintentional manmade disasters (i.e. aircraft crash, train derailment, building explosion) and intentional man-made disasters or terrorist bombing events (i.e. World Trade Center, Oklahoma City, Centennial Olympic Park, Boston Marathon Bombing). Data regarding the medical response to the 9/11/2001 attacks has driven changes in plans for a large scale attack or disaster. Even smaller numbers of injured patients arriving simultaneously may rapidly overwhelm some trauma centers. It is likely important to look at small scale multiple casualty incidents as well to ensure that patient care is not affected on a very frequent basis. For example at one urban, academic, trauma center, pairs of two patients presenting less than 10 minutes apart accounted for 8.9% of all trauma contacts and clusters of three patients presenting within 30 minutes accounted for 2.7% of trauma contacts. **(Shoher 2006)**

Examination of data from the unfortunately too common school shootings (i.e. Columbine, Virginia Tech, Sandy Hook) has helped drive dramatic change in wide sweeping policy for both healthcare and non-healthcare response to these situations. The Hartford Consensus has now published numerous papers and, more importantly, gotten the medical (i.e. EMS) and non-medical (i.e. police) responders on the same page with the goal of improving survival from active shooter events. The acronym THREAT reminds all responders of the prioritized list of actions: 1) threat suppression; 2) hemorrhage control; 3) rapid extrication to safety; 4) assessment by medical providers; 5) transport to definitive care. **(American College of Surgeons 2015)**

Table 4 summarizes the information available and most important data gaps of the three most important trauma-specific data repositories in the United States, including 2 civilian (NTDB And NEMSIS) and military registries. **Table 5** provides the broad overview of what types of data should be collected, at which phases of care, and by whom.

Table 4 Information on Current Major Trauma-Specific Data Repositories in the United States

	NTDB	NEMSIS	JTS DoDTR and JTS PHTR
Owner	ACS-COT	NHTSA	JTS
Time Frame	In-hospital only	Pre-hospital only	Prehospital (Role1), Pre and Inter-facility Transport, Hospital (Role 2, 3, and 4)
Can it be collected electronically / imported from existing patient care record?	Yes/No (some elements)	Yes	Yes, has this capability, but is limited by TMDS expeditionary framework
What does it link to?	NEMSIS	NTDB, HL7 CDA	Seamlessly integrated to Specialty Modules; can import export with external organizations.
How important?	very	very	very
How much coverage by % of patients?	moderate (all ACS-COT trauma centers) In 2013, 758 hospitals submitted data to the NTDB; 230 Level I, 265 Level II, 205 Level III or IV centers..	near complete (an estimated 87% of all 911 activated EMS responses occurring in the U.S. are included)	100% for those admitted to a Role 3 that met inclusion criteria of DOA, DOW, transfer, admit of ICD 9 code 800-995 when JTTS teams are in combat theater. Otherwise, near complete for OCONUS combat and non-combat casualties. Nominal for CONUS non-combat casualties.
What are the coverage gaps?	Only trauma centers. Does not cover non-trauma center hospitals. Only index hospitalization, does not capture readmissions. Does not include patients seen and discharged from Emergency Department. Does not link data for transfers (cannot tell it is the same patient who left a level 3 center and arrived at a level 1 center). No prehospital deaths.	Does not adequately capture interfacility transfers, critical care transfers and air medical care. Only covers patients transported by EMS. No data on patients with “self” transport mode or police vehicle.	2012 - Mandate for Role 2 data, retrospective entry occurring now. 2012 - Initiated Trauma Infectious Disease Outcome Study (TIDOS) module 2013 - Started including prehospital (Role 1) data. 2013 - Initiated military orthopedic trauma registry (MOTR) module 2015 - Started including Rehab Facility (VA) data. 2015 - Initiated Acoustic module

Table 5 Types of Data to be Collected

	Who can provide data?	Time Frame
Non-trained Bystander Care (public)	EMS	very short-term
Death without EMS or hospital care	Coroner or Medical Examiner	very short-term
Trained EMS care	EMS	very short-term
Hospital Care	Hospital	short-term
Rehab Care	Rehab center or Health System	long-term
Outpatient Care	Health System	long-term
Readmissions	Health System, health information exchanges (HIE)	long-term
Long-term mortality	Death records, coroner/medical examiner	long-term

Data Points and Data Groupings that can be Collected

Trauma data can be grouped and evaluated by occupation and recreation. For the military, data can be grouped by battle injury, OCONUS non-battle injury, and CONUS non-battle injury. Data points collected should include injury demographics, anatomic and physiologic parameters, and trauma care and outcomes across the continuum of combat and non-combat casualty care. Mechanism of injury, injury, injury severity, injury patterns, signs and symptoms, medical capability/treatments provided, interval time to capability (facility and treatment/procedure), and response to capability (short and long term outcomes of morbidity, as well as mortality) are also data points that can be captured.

For the military sector, data can also be collected by event (e.g. war-Somalia, Iraq, Afghanistan; battle-Battle of Mogadishu 1993, Battle of Takur Ghar 2002, Battle of Baghdad 2003, Battle of Fallujah 2004, Battle of Abbas Ghar 2005, etc.), operation (offensive, defensive), or phase of the mission (e.g. infiltration, actions on the objective, exfiltration). Offensive operations include movement to contact, attack, exploitation, and pursuit. Defensive operations include area defense, mobile defense, and retrograde operations. It is notable that initial entry operations into immature theaters and retrograde actions and drawdown of assets from a theater can result in spikes in injuries and case fatality rates, and boluses of casualties can result from hostile and non-hostile aircraft mishaps during infiltration and exfiltration. Specific operations, such as airborne operations can also be evaluated for opportunities for performance improvement. **(Kotwal 2004, Malish 2006)**

Personnel, training and equipment available to military and civilian trauma systems, prehospital and hospital settings, environmental conditions and threat (safe or permissive versus unsafe or hostile or non-permissive) can all have an impact on care and morbidity and mortality. Data collected from multiple scenarios can drive predictions and contingency planning for future events. For prehospital efforts, organizing chaos at and near the point of injury can be initiated during data-driven contingency planning with whole community understanding of roles (nonmedical and medical first responders; field care and casualty collection points; evacuation plans, routes and medical and nonmedical platforms (air, ground, water). For intra- and inter-

hospital efforts, data-driven contingency planning can occur for expansion of and outreach from community facilities and resources.

Strengths and Weaknesses of Data Collection Methods

Manual Data Extraction

For the most part, civilian hospital trauma registries continue to rely on a manual abstraction process that requires a registrar to review an existing patient medical chart and abstract pertinent information into the trauma registry software interface. There are both limitations and advantages to this approach when considering the accurate and reliable collection of injury information from hospital records. These advantages and limitations, in general, also apply to other healthcare environments that may be utilized to obtain injury related information.

When considering limitations, manual data re-abstraction is often cited as costly, in terms of personnel and needed resources, and is also considered error prone. The precision of abstracted data often suffers since redundant (but conflicting) information can be found in different areas of a medical chart. For example, a registrar may record "location of injury" from the Triage Form, Trauma Flow Sheet, Billing Sheet, or from the ED Nursing Notes, all of which may not provide a similar description of the injury location. Data reliability is also suspect. Studies demonstrate that inter-rater errors (independent registrars abstracting the same record) and intra-rater errors (one registrar abstracting the same record at different time periods) are significant. **(Thomas 2002)** A recent study of 50 trauma registrars at different trauma centers examined inter-rater reliability of data abstracted from a single fictitious case. The overall accuracy for all tested elements was 64%. Variability was found for 7 of the 8 specific data elements studied including 1) Prehospital, 2) Prehospital vitals, 3) Emergency department procedures, 4) AIS coding for heart injury, 5) AIS coding for lower extremity, 6) length of stay, 7) External cause code. **(Arabian 2015)**

An important advantage to manual record abstraction is the need for precise and reliable measures of injury severity. Studies demonstrate that when an Abbreviated Injury Score (AIS) or an Injury Severity Score (ISS) are auto-calculated relying on billing ICD-9-CM codes, rather than a thorough review of injures listed in the medical record narrative, injury severity is underestimated. **(Mullins 1995)** Also, manual abstraction systems allow for data system (and data dictionary) tailoring, which often results in the development of non-standard definitions, code sets, and thus, data abstractions. This type of tailoring often proves to be a disadvantage since data comparison may not be possible within a system over time or across independent systems.

Electronic Data Export

The current Federal incentives to move towards electronic health records (EHRs) facilitate many advantages when considering injury data collection. The exchange of data elements across two electronic systems is considered efficient since real-time data transmission and availability (i.e., machine-to-machine transmission) can occur 24/7. Data exchange systems can rely on peer-to-peer models, value-added networks, or even internet-based systems. The likelihood of data errors is reduced because data are not abstracted and business rule engines can structure how, when and where data are abstracted and exchanged. Limitations (i.e., barriers) to the implementation of health information exchanges include need for changes to business processes and the preliminary expense and time for exchange setup. Other human oriented

limitations relate to the reluctance to conform to the requirement of a consensus among users to ensure process, definitions and data structure harmonization among implementations exchanging data.

Measures of Data Quality

When considering the utility of data available for evaluation, the quality of the data should be considered along five dimensions:

1. Accuracy - refers to the extent to which recorded data reflect the actual underlying information. Imprecision in data collection invites that introduction of random and systematic error generation.
2. Completeness - refers to the extent to which relevant records are present and the fields in each record are populated appropriately. Partial data collection will produce incomplete information, resulting in a fractional understanding of the topic under investigation.
3. Consistency - refers to the need to obtain and use data that are clear and well defined enough to yield similar results in different settings. Unreliable data results in an inability to compare cases over time, to each other, or reproduce an individual case.
4. Uniqueness - refers to the objective of capturing data once, without unwanted data duplication, and ensuring its application to all required applications. Duplicate data collection in disparate registries leads to unnecessary costs, introduction of random/systematic error and redundant data analysis and reporting.
5. Timeliness - refers to the need for timely data availability and use. Even slightly dated data availability and use begins to degrade the array of uses for which the data can be applied.

Although data quality is vitally important to ensure validity, consistency and generalizability; data quality often falls short of optimal for a variety a reasons. Data sources are often collected in different formats, to meet different objectives, with little forethought regarding interoperability. **Appendix IV** highlights methods that can be employed to link independent datasets, enhance data interoperability and reduce the effect of missing or inaccurate data.

HUMAN SUBJECTS PROTECTION ISSUES QUALITY IMPROVEMENT RESEARCH

Research has many definitions, but usually includes the systematic collection and analysis of data in order to create and answer a specific question, creating and disseminating new knowledge. Human subjects research is under control of the Department of Health and Human Services (HHS), with oversight of individual institutional review boards (IRBs) by the Federal Drug Administration (FDA). The underlying backbone and ethical framework has been the Nuremberg Code and the Declaration of Helsinki and the Belmont Report and the current regulations are known as “the common rule.” One of the main basic tenets is that patients will consent to be research subjects. This approach was in response to interventional studies done on unwilling and often unknowing participants in the dark days of medical research. Well known examples of these atrocities include research done in Nazi Germany and in the Tuskeegee syphilis experiments in the United States. Some emergency research cannot be performed after informed consent by the research subject due to the severity of illness/injury (i.e. cardiac arrest

or severe traumatic brain injury) and the time delays to treatment. Therefore, the U.S. government has created specific rules and regulations that do allow some research to be performed under waiver of consent after a prolonged community consultation, although the process is often dramatically more difficult to do.

More recently, there is an understanding that high-impact research can be done on data originally collected in routine medical care to provide insight and new medical knowledge. In general, the use of pre-existing human subjects data for research purposes may be approved by individual IRBs under some circumstances. These research project continue to require approval and oversight from a local IRB. While the regulatory environment is robust to ensure research safety, there are no current regulations that cover the use of pre-existing patient data for operational analysis. Hospitals are free to use any available data for projects to examine numbers of patients, workflow, length of stay and clinical outcomes as long as there is no plan for publication and dissemination (which would be defined as research). These strategies are routinely employed by hospital and health system financial analysts to make major programmatic changes, improve hospital efficiency or to plan staffing and budgets.

There is ongoing debate regarding the use of data for research vs. data for quality improvement (QI). About a decade ago, a large quality initiative was led by Dr. Peter Pronovost and published in the New England Journal of Medicine. **(Pronovost 2006)** This project garnered much attention and raised dramatic controversy. One side claimed that the intervention (application of a bedside checklist before central line insertion) was unethical since patients were not informed it was to be used and they did not give individual consent. The other side stated that the researchers had IRB approval and followed appropriate protocols since patient level data was aggregated to an ICU level and de-identified before it was shared with the research team. This example has since been examined and studied as a pivotal case in the transition of QI into a *bona fide* research science and how the governmental oversight will ensure the protection of human subjects without impeding the progress of the research into QI. **(Kass 2008)** Since then, the distinction between QI activities and research has become even more blurred as many QI projects go on to be published in peer-reviewed research journals. This is frequently allowed if the QI team obtains IRB approval to perform research on the pre-existing data which was originally collected under the rubric of QI. Some local IRBs now have explicit instructions to help physicians decide if the primary goal of their work is QI or research. For example, the Johns Hopkins University School of Medicine IRB has a flow diagram to help answer the question: "Does my quality improvement project need IRB approval?" (http://www.hopkinsmedicine.org/institutional_review_board/guidelines_policies/guidelines/qaqi_flowchart.pdf)

The controversy regarding the oversight of registry based research is ongoing. To some experts, the fundamental question starts with what is the goal of the registry. Is it performance improvement / quality improvement? Or is it research? However, there is a new ethical framework described in a report by the Hastings Center (http://www.thehastingscenter.org/LearningHealthCareSystems) which suggests registry-based research should be allowed without individual consent. This framework was co-authored by a group of bioethicists along with input from QI researchers and advocates for comparative effectiveness research. It has two explicitly stated goals: 1) "to support the transformation to a learning healthcare system" and 2) "to help ensure that learning activities carried out within such a system are conducted in an ethically acceptable fashion." **(Faden 2013)** The general ethical concept is that health care providers have a moral imperative to study and improve the delivery

of health care and that patients have a moral obligation to have their data used for this type of research in a learning health system.

The federal government is currently in the process of re-examining these issues. **(Emanuel 2015)** They have solicited input from researchers, bioethicists, and other key stakeholders to inform possible changes to the rules governing research on human subject protections, known as "the Common Rule." The current regulations have been in place since 1991 and are followed by numerous federal agencies. The proposed topics for possible change include: "1) calibrating oversight to the level of risk; 2) enhancing respect for research participants; 3) facilitating broad participation in research; 4) increasing privacy and security safeguards for research with biospecimens and data; 5) simplifying while improving readability of consent documents; and 6) streamlining IRB review."

THE SCIENCE OF QUALITY IMPROVEMENT: HOW TO IMPLEMENT BEST PRACTICES, HOW DATA IS USED TO INFORM CHANGE IN PRACTICE

Although most patients and clinicians now consider QI efforts a mandatory part of healthcare, when forward-thinking visionaries first proposed these concepts in the 1980s, these ideas were met with skepticism. It has taken decades for these ideas to be accepted. Suggestions by early proponents such as Don Berwick that top leaders should embrace QI and devote substantial time and financial investments have taken decades to agree upon. **(Berwick 1989)** Some of the early learning points about changing systems rather than people, defining clear goals, and concentrating on patients are now fully integrated into our healthcare system. **(Berwick 1996)**

Within the past few decades, the young science of QI has been gaining traction. Since the IOM reports "To Err is Human" and "Crossing the Quality Chasm: A New Health System for the 21st Century" greater interest, focus and funding has gone towards the "triple aim" including care, health, and cost. **(Berwick 2008)** One of the thought leading groups in the arena is the Institute for Healthcare Improvement (IHI). They clarify the triple aim and define it as 1) Improving the patient experience of care (including quality and satisfaction); 2) Improving the health of populations; and 3) Reducing the per capita cost of health care. (www.ihi.org) The IHI suggests the Model for Improvement as the framework to guide improvement work. One useful, rapid-cycle method to attack quality issues is the Plan-Do-Study-Act (PDSA) approach.

The Role of Implementation Science / Knowledge Translation

The stepwise framework of translational medicine has often followed the National Institute of Health (NIH) definition of translational research as the movement of discoveries in basic research to application at the clinical level. This pathway frequently stopped when a drug, surgery, or procedure was shown to be effective in a clinical research studies. A new appreciation now exists from clinical researchers, health care leaders, and governmental funders for the critical step of integration into widespread practice to population level. **(Dougherty 2008)** The National Quality Forum (www.qualityforum.org) suggests that collaboratives can be a useful tool to provide data, give feedback, benchmark against peers, and share best-practices. **(National Quality Forum 2015)**

Integration of new knowledge to change everyday clinical practice in a healthcare system does not come easily. In addition to knowledge deficits that must be addressed, there are

numerous other barriers that must be overcome to make sustained change. These types of barriers include structural, organizational, peer group, professional and professional-patient interaction barriers. **(Grimshaw 2012)** Many clinicians realize the institutional memory, culture, pride, and ego that often gets in the way of optimal patient care. Approaches towards the knowledge transfer process, often referred to as "implementation science" include principles from organizational behavior that can help to communicate results and effectively influence change. The science of knowledge translation has grown dramatically in the last decade. Numerous books, journals, websites, course, and conferences are now dedicated to the field as it applies to medicine. One leading organization in the field of QI work is the IHI whose vision is that "everyone has the best care and health possible" and and their mission is to "improve health and health care worldwide." (www.ihi.org) Within the United States, there are numerous healthcare systems known as leaders in the field. The National Quality Forum's report, "Data Needed for Systematically Improving Healthcare," offers Virginia Mason Medical Center in Seattle as a prime example of a health system that fully embraces the idea that better care is delivered by systems approaches. **(National Quality Forum 2015)** Intermountain Healthcare, another major player in the field, is led by a team of well known physician and non-physician leaders in quality. Their chief quality officer, Brent James, has helped promulgate the importance of using data for QI efforts. **(Berwick 2003)**

Numerous ideas about approaches to improving healthcare come from collaboration between experts both from divergent medical specialties and other disciplines. While some efforts are physician led, there are also aspects run by non-physician clinicians (i.e. nurses), health service researchers, human factors engineers, and social scientists. The importance of this widely disparate approaches is quite beneficial and leads to projects addressing multiple areas of potential defects. One example of how to break down QI efforts is into one of six domains as suggested by Batalden: 1) structure of improvement knowledge; 2) discovering and defining sources of evidence; 3) social determinants of action; 4) importance of cross-disciplinary work; 5) challenges of professional education; and 6) rethinking methods of inference. **(Batalden 2011)**

Many options have been suggested as possible frameworks to standardize the approach to change. These approaches often have one of three general aims: 1) to describe or guide the process of translating research into practice; 2) to explain what influences implementation outcomes; and 3) to evaluate outcomes after implementation. **(Nilsen 2015)**

The Translating Research (Evidence) into Practice (TRIP) model is well-accepted approach used by many QI groups to help drive change. **(Pronovost 2008)** Although a thorough explanation of the TRIP model is beyond the scope of this work, it is useful to understand the basic premise. The TRIP model clearly deliniates a four step process for how to change practice: 1) Summarize the evidence, 2) Identify local barriers to implementation, 3) Measure performance, and 4) Ensure all patients receive the interventions. It is important to realize the reliance on reliable data in two of the four steps of this approach. The critical first step is to summarize the evidence using data to "identify interventions associated with improved outcomes." This identification phase may find data from many types of clinical research. Rarely, there will be high-quality RCT data. More likely there is data from comparative effectiveness research studies using observational studies such as cohort studies and/or large database analyses. Ideally this data compilation step is done via a formal systematic review and meta-analysis, if possible. The crucial third step measures data to determine if the implementation has

succeeded and what impact has occurred. Without hard data, quality improvement efforts are driven by opinion and anecdote, rather than science. **(Pronovost 2009)**

Once a quality improvement intervention has been performed, and if the results are positive, one common method to start disseminating the findings to others is through the publication of a peer-reviewed manuscript in the medical literature. These papers can be classified into one of three main types: 1) innovation, 2) testing, and 3) scale-up and spread. As can be expected, many projects are attempted and fail at the innovation phase. A smaller number make it to the testing phase, and only the rare innovations pass muster enough to warrant widespread implementation and scale-up onto a national stage. Parry et. al. suggest examining QI efforts using a modification of Kirkpatrick's Framework of assessing educational interventions. They propose considering the following topics/questions: 1) experience—what was the participants' experience? 2) learning—what did the participants learn? 3) behavior—did they modify their behavior? and 4) results—did the organization improve its performance? **(Parry 2013)** One important skill set for all readers of the medical literature is understanding both how to write **(Holzmueller 2013)** and read **(Fan 2010)** a manuscript about quality improvement study.

Using Data for Comparative Effectiveness Research (CER) in Trauma

Simply, having access to vast amounts of data is not enough to make meaningful use of data to impact care. The data must be aggregated and presented in such a fashion that they become actionable. One method is the research approach in which epidemiologists and/or biostatisticians work with clinical researchers to ask questions that can be answered by testing hypotheses using data analytic tools.

Clinical trauma care providers make an incredible number of decisions, many requiring split-second decisiveness, when caring for an injured patient. Ideally, there would be strong evidence from a systematic review of RCTs to support every decision, although that is rarely, if ever, the case. When RCT supported data are not available, research from the discipline of comparative effectiveness can play an important role to guide decision making. The goal of CER is to provide evidence on the effectiveness, benefits, and harms of different treatment options to inform health-care decisions. Evidence can come in two main types. Researchers can perform a systematic review to compile all available evidence about the benefits and harms existing clinical research. Researchers can perform original studies to create new evidence of comparative effectiveness of a test, procedure, or treatment algorithm.

CER studies use data to test hypotheses using a wide array of study designs and biostatistical analytic tools. RCTs are performed by assigning patients to a specific treatment group, then following the patients over time to determine differences in outcomes based on the treatment group to which they were assigned. Although RCTs are considered the gold-standard in clinical research, they are often impractical, unethical, or too costly to perform for every possible question that may arise. **(Berwick 2008, Haut 2011)** In that case, other research designs may be preferable, or the only realistic option, on which to base a decision. Prospective observational cohort studies do not assign patients to a specific treatment arm, but do identify a group of patients and follow them over time to determine their outcomes. This type of study can prevent common biases often encountered when data are collected after the fact, in retrospect.

The most highly visible and cited project of this type in trauma was the National Study on the Costs and Outcomes of Trauma (NSCOT). The research team showed that trauma center care is associated with lower mortality than for patients treated at non-trauma center hospitals.

Projects such as these carry a high price tag due to the study design to prospectively collect data in a standardized fashion. The NSCOT study was funded by the CDC and the NIH. However, as the adage goes, "you get what you pay for." The quality of the study was top notch and the research question was not answerable in any other way since there was no pre-existing dataset that would have allowed this comparison. **(MacKenzie 2006)**

An alternative, less expensive approach is to analyze existing data to examine a research question or to test a research hypothesis. Many large database studies have been performed and published in trauma care, many utilizing the American College of Surgeons' NTDB. One benefit of studies such as these is their low cost, since no new data need to be collected. However, this poses a potential downside; since no large-scale funding is required, they can be performed without much forethought, oversight, external review, and scientific rigor. Unfortunately, there is wide variability in the quality of these peer-reviewed publications. Some rigorous, well-done studies are published in high impact journals, **(Galvagno 2012, Haut 2011)** while many are of lower quality and published in lower tier journals.

Recently, a series of papers have provided a suggestion about the "best practice approach to NTDB research." The group began with a systematic review of all published NTDB papers and identified 286 NTDB publications, 122 of which performed a multivariable adjusted analysis. There were considerable differences in the covariates used for case adjustment. Nearly half (43%) of the studies did not control for the five basic covariates (age, sex, any type of anatomic severity, any type of physiologic severity, and mechanism or type of injury) necessary to conduct a risk-adjusted analysis of trauma mortality. In addition, under 10% of studies used appropriate statistical methods such as clustering to adjust for facility effects or imputation to deal with missing data. **(Haider 2012)** The group then performed an NTDB analysis which determined that the best risk adjustment model with the smallest number of covariates to model trauma patient mortality. The model includes only six covariates (age, hypotension, pulse, total Glasgow Coma Scale [GCS] score, Injury Severity Score [ISS], and a need for ventilator use) yet still shows excellent discrimination between trauma survivors and nonsurvivors. They conclude that "analytic standardization may prove critical in implementing best practices aimed at improving the quality and consistency of NTDB-based research." **(Haider 2014)** In his plea to improve the science of large database analysis, Adil Haider implores us to "demonstrate our commitment to improving the quality of science arising from the NTDB." **(Haider 2013)**

Inherent limitations of the data are often the lynchpin differentiating a large database study that is informative, rather than one that may be potentially incorrect with flawed inferences. For example, changes in billing and coding practices over time may invalidate some studies examining temporal changes in disease prevalence, treatments, or outcomes. **(Sarrazin 2012)** Systematic undercoding of inexpensive medical procedures leads to missing data on these "minor" procedures (i.e. computed tomographic scans, electrocardiography, ultrasound). **(Haut 2012)** This limitation of administrative databases must be considered since ignoring it may lead to invalid attempts to examine practice variation in their use or attempt to control for procedure volume to overcome surveillance bias in outcomes reporting. **(Haut 2011)**

Why must we collect and use cost data?

In the current era of healthcare, cost is a reality that must be dealt with. Long gone are the days when physicians could simply ignore the cost of the services they provide. Clinicians are getting the message loud and clear that cost must taken into account in many different facets. Individual doctors, researchers and policy makers need to consider the value defined as outcomes

relative to costs (Value = Outcomes/Cost) as this also encompasses efficiency. **(Porter 2010)** One way in which cost data can be examined is in the realm of cost effectiveness research which is a critical component of comparative effectiveness research. Cost-effectiveness analyses compare the "health effects that result from alternative uses of a given amount of health resources." Since resources are limited, this type of research is critical to help individual patients, clinical providers, and policy makers decide on optimal care delivery on an individual or health system level. **(Garber 2010)**

Unfortunately, trauma researchers are hindered by available data with which to perform high-level, national cost effectiveness research. Currently, the NTDB and NEMSIS have no data on cost of care. This inherent limitation of the data set severely hampers any research within the cost effectiveness realm. Some researchers have turned to other large administrative databases (i.e. the National Inpatient Sample [NIS], Nationwide Emergency Department Sample [NEDS]) to examine cost of care issues in trauma. **(Haider 2015, Obirieze 2012, Glance 2011, Peterson 2015)** However, most administrative datasets do not contain enough precision of data on injury severity or physiologic derangement. The injury severity component can be dealt with using some statistical models to estimate ISS or use other methods of risk adjustment (i.e. survival risk ratio, Barrel matrix). But the critically important physiological data (i.e. heart rate, blood pressure, GCS) that trauma know affects outcomes is missing and cannot be included. Linkage of ALL available data (including cost information) on an individual patient's episode of care would alleviate this issue and allow higher-quality cost effectiveness research to inform policy and drive the value in the current cost constrained environment.

The NSCOT study contains prospectively collected clinical and cost data for injured patients treated at both trauma and non-trauma centers. These data have been utilized to provide some of the most interesting and informative studies on the cost of trauma care. It is well known that trauma center care is costly, but is also been shown to save lives **(MacKenzie 2006)** raising questions about the value of trauma care. In 2010, MacKenzie examined the overall cost effectivenss of treating patients at trauma vs. non-trauma centers. They found that the added cost for treatment at a TC versus NTC was $36,319 per life-year gained ($790,931 per life saved) and $36,961 per quality-adjusted life years gained. They "provide evidence that regionalization of trauma care is not only effective but also it is cost-effective." **(MacKenzie 2010)** Future studies such as these can only be performed if adequate data is available to trauma researchers.

If cost effectiveness questions are to be answered, then cost data must be prioritized to be included in all data sets. However, before making this recommendation, the cost of obtaining the data needs to be considered. Every additional data element costs money to collect and must be considered before deciding to add data elements to any database. This concept is known as the Value of Information (VOI), defined as the amount a decision-maker is willing to pay for information prior to making a decision. It includes a number of analytic tools which can help to assess the value of "acquiring additional evidence to inform a clinical (or public health) decision." **(Minelli 2015)**

Practice Management Guidelines as a Framework for Improving Trauma Care

Clinical medicine changes rapidly, requiring physicians to spend many hours just trying to keep up with the most current care expectations. Clinicians have countless resources to choose from and often unable to keep up the astounding amount of published data on which to base evidence-based clinical decisions. This rapid growth in medical literature drove the evidence-based medicine movement to help busy clinicians apply the best evidence when making clinical

decisions. One aspect of evidence-based medicine is the creation of evidence-based clinical practice guidelines (CPGs) or practice management guidelines. These reference works synthesize existing data in order to help change clinical practice, with goals of and reducing suboptimal practice variations and optimizing care for patients. There are well accepted approaches to guideline development. The Institute of Medicine published a report titled "Clinical Practice Guidelines We Can Trust" in 2011 which gives suggestions for how to create guidelines. **(Institute of Medicine 2011)** This report puts forth 8 standards that should be employed by PMG developers including: 1) Establishing transparency; 2) Management of conflict of interest; 3) Guideline development group composition; 4) Clinical practice guideline–systematic review intersection; 5) Establishing evidence foundations for and rating strength of recommendations; 6) Articulation of recommendations; 7) External review; and 8) Updating.

One well-accepted approach is "The Grading of Recommendations Assessment, Development and Evaluation" (GRADE) method. The GRADE Working Group began in 2000 as an informal collaboration of healthcare researchers with the goal of addressing the shortcomings of the current grading systems. The group has developed an overall approach to grading quality of evidence and strength of recommendations. Many national and international organizations have formally endorse GRADE as the system of choice for guideline development. (http://www.gradeworkinggroup.org/index.htm) The list of endorsers include federal agencies (i.e. AHRQ, CDC), professional societies (i.e. ACCP, SCCM), and international organizations (i.e. WHO, Cochrane Collaboration). Even with these recommendations, it is often difficult for specialty societies to create important guidelines. **(Classen 2015)**

The *de facto* leader in trauma guideline development has been the Eastern Association for the Surgery of Trauma (EAST). EAST has been creating and publishing its Practice Management Guidelines (PMGs) for over twenty years since the mid 1990s. **(Kerwin 2012)** EAST has published over 45 PMGs, all of which are freely available via The Journal of Trauma and Acute Care Surgery (http://journals.lww.com/jtrauma/Pages/collectiondetails.aspx?TopicalCollectionId=3) and the EAST website (www.EAST.org) which is optimized for mobile use to allow rapid use in an emergency setting. Many EAST PMGs are indexed in the National Guideline Clearinghouse (http://www.guideline.gov) which is a free public resource run by the AHRQ. EAST adopted and embraced the GRADE methodology **(Kerwin 2012)** and recently has published "Writing an EAST Practice Management Guideline (PMG): A Step-By-Step How-To Guide" as a resource for all GRADE-based PMG developers. **(Callcut 2015)** Other groups have also started to create some trauma care GRADE-based guidelines. **(Bulger 2014)**

The importance of dissemination cannot be underestimated. A guideline that no one reads, adopts, and uses is not beneficial to patients. The rapid dissemination of PMGs via the routine publishing in mainstream peer-reviewed setting is necessary, but may not be sufficient to change practice. More rapid sharing of new scientific knowledge is spreading faster due to the world of social media. Many publishers are taking note of alternative individual article-level metrics to assess the impact of their papers well before they see a spike in the journals' impact factor, sales, or readership. The following two recently published EAST trauma PMGs are the two top-scoring articles based on Altimetric scores in the Journal of Trauma and Acute Care Surgery: "Cervical spine collar clearance in the obtunded adult blunt trauma patient: A systematic review and practice management guideline from the Eastern Association for the Surgery of Trauma." **(Patel 2015)** and "An evidence based approach to patient selection for

emergency department thoracotomy: a practice management guideline from the Eastern Association for the Surgery of Trauma." **(Seamon 2015)**

Changing Clinical Trauma Care with Data Using Data To Compare Trauma Processes of Care and Outcomes

Utilizing data from the ACS-TQIP, research led by Shahid Shafi has demonstrated that risk-adjusted mortality rates are nearly 50% higher at some designated level 1 and 2 trauma centers compared with other centers. **(Shafi 2008)** These centers are all ACS-verified Level 1 or Level 2 trauma centers and therefore have similar structures (using the Donabedian terminology). The researchers hypothesized that wide variations in risk-adjusted patient outcomes were most likely explained by variations in processes of care. This group has performed an elegant series of analyses, which show that there are significant variations in clinical practices and gaps in adoption of evidence-based practices at trauma centers.

In one retrospective observational study conducted at 5 Level I trauma centers across the United States, they found that compliance with 22 commonly recommended clinical practices for traumatic brain injury, hemorrhagic shock, pelvic fractures, and long-bone extremity fractures ranged from 12% to 94%. Patients who received all recommended care were 58% less likely to die. More importantly, after adjusting for patient demographics and injury severity, each 10% increase in compliance with recommended care was associated with a 14% reduction in risk of death. **(Shafi 2014)** In another study, the group measured compliance with 6 management guidelines for severe traumatic brain injuries in 11 Level I trauma centers. They found that the overall compliance rate with evidence-based guidelines was 73% with wide variation among centers. Compliance with individual processes of care ranged from 52% to 92%. Multivariate analysis again showed that each 10% increase in adoption of evidence-based guidelines was associated with a 12% reduction in mortality. **(Shafi 2014)** In their third study, they surveyed 55 trauma centers to determine their adoption of 32 evidence-based management protocols. They reported huge variation in the adoption of protocols for trauma care. Only one center was compliant with all 32 management protocols. About half of the centers were compliant with about half of the protocols studied (range, 4 to 32). **(Sobrino 2013)**

The group's next goal is to embark upon the burgeoning science of knowledge translation in surgery to truly impact the care of the injured patient. **(Black 2012, Sinuff 2013, Brooke 2015)** They plan to drive change by using a combination protocols, clinical practice guidelines, publications, audit and feedback, reminders, continuing medical and professional education activities, academic detailing, organizational change, and bundles, either separately or in various combinations. The group has recently convened a panel of key stakeholders and experts to identify a bundle of care that can be studied in the trauma population.

The Impact of a Large Database Analysis and Guideline on a State Protocol for Prehospital Spinal Immobilization

Routine spinal mobilization of trauma patients has been performed for decades by prehospital care providers although relatively little data exists on its true benefit. The procedure continues based on habit with the idea that it may help prevent furthering of partial spinal cord injuries. However, there is little empirical data to show that this is the case, especially in patients with penetrating trauma. Numerous small retrospective series and opinion papers have presented data which suggest that spinal mobilization in patients with gunshot wounds to the spine

provides little, if any, benefit. However, this had not yet been enough to change clinical practice. The largest research paper on the subject was a large database analysis of over 45,000 patients using the NTDB. This study reported significantly higher mortality associated mortality with prehospital spinal immobilization. Over 1000 patients would need to be treated (number needed to treat) to see the potential benefit (patient with partial spinal cord injury requiring surgery); while there would be one additional death for every 66 patients immobilized (number needed to harm). **(Haut 2010)** Recently, the Prehospital Trauma Life Support (PHTLS) executive committee published a systematic review and guideline on the topic. This manuscript used all available published evidence and data to support a recommendation that spinal mobilization not be routinely performed in patients with penetrating trauma. **(Stuke 2011)** Data syntheses such as these reach the highest level of evidence in the realm of evidence-based medicine and can be used to drive change in clinical practice. For example, trauma surgeon and EMS experts brought these data and the PHTLS recommendations to the the Maryland MIEMMS committee who agreed to change the statewide EMS protocol. The new protocol now clearly states "patients with isolated penetrating trauma should not have spine immobilization performed."

Advanced Trauma Life Support (ATLS): Changing Education worldwide based on trauma data and Comparative Effectiveness Research

Advanced Trauma Life Support (ATLS) is the standardized approach to the clinical management of injured patients worldwide. The course began after an incident in 1976 when a Dr. James Styner, an orthopedic surgeon, was involved in the crash of a 6-passenger airplane in rural Nebraska with his wife and children. He found that the initial trauma care provided at the local hospital was severely lacking; it was closed, and took time to gather personnel to open. Even once the team was assembled, he noted that the doctors had little training in the management of serious trauma. This single incident sparked the beginning of the ATLS, the first prototype course which was taught in Nebraska in 1978. Since then, led in the early days by Paul E. "Skip" Collicott, it has grown to be the premier trauma educational trauma tool of the ACS-COT. In its current 9th edition, ATLS runs approximately 1000 courses, teaching approximately 25,000 students (now including both physicians and non-physicians) each year. ATLS teaches an algorithmic approach for treatment of patients with specific injury patterns, vital signs, clinical exam findings, etc. **(Kortbeek 2008)**

While there is wide agreement about the role of ATLS, there is little empiric data that it has had a proven impact on patient outcomes. The Cochrane Collaboration has published and updated a systematic review with the goal of quantifying the "impact of ATLS training for hospital staff on injury mortality and morbidity in hospitals with and without such a training program." They found no clear evidence that ATLS or similar programs impact the outcome for victims of injury." The authors call for more research on the "evaluation of trauma systems incorporating ATLS, both within hospitals and at the health system level, by using more rigorous research designs." **(Shakiba 2004, Jayaraman 2009, Jayaraman 2014)**

Although begun with mainly expert opinion-based treatment algorithms, ATLS has adjusted its approach. In the current 9th edition, dramatic changes to some of the basic tenets of trauma care have been made, based on examination of trauma data. **(The ATLS Subcommittee, American College of Surgeons' Committee on Trauma, and the International ATLS working group 2013)** The course has taken a much more evidence-based medicine approach to changing its recommendations. There are numerous examples in which old dogma has been replaced with suggestions based on data-driven evidence. There are dramatic changes to many

phases of care including airway management, hemorrhage control from pelvic fracture, tourniquet use, and others. The most dramatic change is probably that the standard, immediate 2-liter intravenous fluid bolus which had been mandated for all injured patients is now replaced with a “balanced resuscitation” or “damage control resuscitation” approach. These modifications are based on new data, much of which has come from the military.

The Promise of the Idealized Electronic Health Record

Electronic health record (EHR) systems have been touted as having the potential to revolutionize healthcare delivery by enabling the rapid and reliable access to information at the individual patient and population levels. **(Institute of Medicine 2001)** The promise of better information is not without merit; currently we collect more data in healthcare than has ever been collected in the history of medicine. Only by leveraging the full power of health information technology can these vast amounts of data be analyzed, transformed into usable information, and disseminated to the appropriate individuals. **(Grumbach 2014)**

The fundamental goal of clinical data collection in EHR systems is to generate usable information to facilitate better decision making. The “Five Rights” of clinical decision support are well-accepted as providing the right information, to the right person, in the right format, through the right channel, at the right time in the workflow. **(Campbell 2013)** However, EHR systems have generally fallen short both from what was promised and what is needed. **(Pronovost 2014)** Free markets enable organizations to select the most appropriate EHR vendor for their needs, however across healthcare settings EHR systems – even those purchased by the same vendor – are different and all too often cannot integrate or share data. Healthcare organizations work with vendors to customize methods of data collection and information use in EHR systems to meet the specific needs of their organization. Hospitals and healthcare systems are afforded the opportunity to collect and use data specific to the needs of their patient populations and demands of their clinical staff, particularly at larger health systems where the purchase and implementation of EHR systems can easily exceed $1 billion. **(Koppel 2015)** However, customized data fields often do not easily translate between organizations using EHR systems from a single vendor and certainly do not translate between organizations using EHR systems from different vendors. **(Sheikh 2015)** Despite the rapid adoption of EHR systems in hospitals across the country, the issue of interoperability remains the greatest single challenge to building a truly unified master medical record for individual patients.

In an effort to overcome some of the challenges associated with a lack of interoperable EHR systems, regional health information exchanges (HIE) have emerged as tools for clinicians to circumvent the major limitations of interoperability on clinical medicine. Three broad categories of health information data exchange are commonly discussed. Directed exchange covers the concept of providers sending/receiving secure information electronically to support coordinated care. Consumer mediated exchange platforms (i.e. Google Health, Microsoft HealthVault) support the ability of patients to electronically aggregate and share their health information with providers. Query-based exchanges allow providers to find information on a patient from other providers. This query-based exchange has been suggested as one of the most critical, especially for unplanned/emergency care. This system would be immensely helpful to frontline trauma providers to rapidly access a acutely injured patients health history and medications. For example, knowing that a patient with a traumatic brain injury is taking anticoagulant drugs at baseline could dramatically change clinical management leading to improved clinical and functional outcomes.

When providing care, clinicians make countless critical decisions every hour that may directly impact the outcome for their patient. Providers require information in real-time that is accurate, complete, and meaningful in order to make the best decision every time for their patient. The ability of the current EHR systems to collect, store, analyze, and – most importantly – share patient-level data are at best inefficient and at worst unsafe. To improve the usefulness of clinical data, several steps should be taken. First, all EHR systems should be required to ingest data from all other EHR systems. Second, a national master patient index should be developed to identify patients within and between healthcare settings to facilitate joining health data from multiple sources. Third, a national data repository should be established to hold the master medical record for all patients in the U.S. with data supplied by inpatient and outpatient organizations, and pharmacies. Fourth, policies should be set in place to grant authorized providers access to view identified data from the master medical record. Fifth, policies should be set in place to grant authorized investigators access to view de-identified data from the master medical record for quality improvement and research purposes. Put simply, the concept of a single, unified patient medical record would be a dream come true.

Decision Support Tools, Predictive Analytics, and Personalized Medicine

Some of the most successful decision support tools are simple, paper-based checklists. Central line-associated bloodstream infections (CLABSIs) have been nearly eliminated in ICUs around the world with the use of a simple 5-item checklist performed at the time of line insertion. **(Pronovost 2006)** The 19-item surgical safety checklist was designed to improve team communication and consistency of care. It was rigorously tested in a eight hospitals representing a wide variety of hospital and patient populations in the World Health Organization's Safe Surgery Saves Lives program. The group prospectively collected data on clinical processes and outcomes from over 7500 surgical patients. Mortality (0.8% va. 1.5%, $p=0.003$) and inpatient complications (7% vs. 11%, $p<0.001$) were both significantly lower after implementation of the checklist. **(Haynes 2009)**

In addition to the role of data for research as a post-hoc analysis, it is critical to have data at the fingertips of healthcare providers to enable them to make the best decisions for their patients in real time. The robust use of advanced clinical decision support tools should be a factor in all electronic health records. Carolyn Clancy, previous director of AHRQ, stated that "Health IT vendors that create clinical software that mirrors or enhances workflow and provide relevant, evidence-based information at the point of care will win acceptance by providers and support better care for patients." **(Clancy 2012)**

One successful example of a computerized clinical decision support tool is its use in prevention of venous thromboembolism (VTE). Many hospitalized patients are at elevated risk for VTE. Numerous evidence-based guidelines have been written summarizing best-practice prevention for VTE. In particular, injured patients are one of the patient groups at highest risk for VTE and should be treated appropriately with prophylactic medications to prevent this deadly complication. **(Rogers 2002)** Unfortunately, it is well known that many hospitalized patients do not get the prevention strategies they should. **(American Public Health Association 2003)** In fact, rates of appropriate care have been reported to be in the 40-60% range. **(Goldhaber 2004, Cohen 2008)** Recently, the AHRQ "Making Healthcare Safer" report suggested that "Strategies to increase appropriate prophylaxis for VTE" should be included on list of top 10 "Strongly Encouraged Patient Safety Practices." (http://www.ahrq.gov/research/findings/evidence-based-reports/services/quality/ptsafetysum.pdf)

In 2008, a multi-disciplinary VTE collaborative implemented a mandatory clinical decision support tool within the hospital's computerized order entry system. They described the entire quality improvement process they went through using the TRIP framework. **(Streiff 2012)** This tool forced clinicians to perform a rapid, checklist-based assessment of risk for VTE and contraindications to pharmacologic prophylaxis. The group found many benefits of their approach. VTE prevention was placed into the workflow allowing rapid, accurate risk stratification and risk-appropriate VTE prophylaxis. It enabled physicians to apply evidence directly to clinical care in a real-time fashion in a real-world setting. Finally, they harnessed the analytic power of the system to directly pull data for performance monitoring and research publication. In fact, the first research published on the program was a comparative effectiveness study involving trauma patients at their academic, Level 1 trauma center. The pre-post study showed a significant increase in proportion of trauma patients receiving guideline-appropriate VTE prophylaxis (62.2% vs. 84.4%, $p<0.001$) There was also an associated drop in preventable harm from VTE (1.0% vs. 0.17%, $p=0.04$). **(Haut 2012)** The Hopkins model has been cited by the AHRQ as a prime example of "effective implementation and clinical decision support." **(Maynard 2015)**

One additional promise of decision support is to equalize care for all patients regardless of their race, sex, and other characteristics. Healthcare disparities are rampant in American medicine. They have been studied and reported in many fields including trauma. However, few interventions have been proposed or implemented that can mitigate these disparities. An additional *post-hoc* analysis of the same trauma VTE prevention data (along with data from an internal medicine cohort) showed that race-based and sex-based health care disparities were eliminated with the decision support tool. Race-based and sex-based disparities were noted in the pre-intervention cohort. After implementation of the decision support tool, there were no differences in the proportion of patients receiving optimal VTE prevention by race or by sex. **(Lau 2014)**

In addition to typical data elements found in a trauma registry, other data elements can be utilized for predicting patient health outcomes. The novel use of new biomarkers in medicine is changing the way clinicians use data at the bedside. The Surgical Critical Care Initiative (www.sc2i.org) at the Uniformed Services University of the Health Sciences Center was established to develop biomarker-driven clinical decision support systems (CDSS) for the critically ill, with the goal of improving clinical outcomes. SC2i is currently using tissue biomarkers as part of a data analysis to improve decision-making algorithms. Although currently focused on trauma, the methods developed may provide insight into how advanced decision support tools can maximize outcomes across multiple disciplines requiring complex medical decision-making.

The group published on a predictive analytic tool that could help surgeons decide when traumatic wounds are ready for definitive closure. Currently, surgeons make this critical decision using visual inspection of the wound along with the general characteristics of the patient. The newly designed tool uses clinical information, serum, wound effluent, and tissue prior to and at each surgical debridement in a much more formulaic manner. Their study found that use of the model "would improve clinical outcomes and reduce unnecessary surgical procedures." They were able to successfully include biomarker data to augment the typical analytic approaches using clinical data alone. **(Forsberg 2015)**

In the VTE prevention example cited above, the decision support tool assumes that there is little variance between individual patients and uses only clinical and demographic data to

suggest optimal VTE prophylaxis. However, new data suggests that there is large individual patient variation in the baseline thrombotic state and response to VTE prevention therapy. Thromboelastography (TEG) is a lab test that provides a series of lab values that have been suggested as adjunct data elements that may inform this decision. Admission TEG mA values can identify patients with an increased risk of in-hospital PE. **(Cotton 2012)** Some patients receiving standard dosing of enoxaparin remain pro-thrombotic, as measured by serial TEG. **(Van 2009)** Other studies of TEG suggest that platelet factors play a larger role in the pro-thrombotic state which may have implications for alternate drug regimen (i.e. anti-platelet agents such as aspirin or clopidogrel) choices for VTE prevention. **(Harr 2013, Allen 2015)** Augmenting a decision support tool with lab data may bring precision medicine to the bedside and improve personalized care of injured patients. Future decision support tools will likely need to include vast amounts of data of many types to ensure that patients receive optimal care. We have been hearing about the promise of the future of precision medicine. Perhaps it is closer than we think and in our reach if we prioritize data to enable it.

How to Implement Best Practices in the Military Setting

As a result of the recent conflicts in Afghanistan and Iraq, there have been multiple advances in battlefield trauma care within the Military Health System that include prehospital and hospital efforts. A DoD Joint Trauma System, a DoD Trauma Registry, novel hospital Clinical Practice Guidelines, Damage Control Resuscitation (DCR), and 1:1:1 (platelet/FFP/PRBC) transfusion are just some of the notable hospital efforts. Tactical Combat Casualty Care guidelines, a Joint Trauma System Prehospital Trauma Registry, advanced providers and care during transport, extremity tourniquets, junctional tourniquets, hemostatic dressings, and use of freeze dried plasma are just some of the notable prehospital efforts. Additionally, civilian and military trauma center rotations for prehospital and hospital personnel have helped to solidify clinical practice and procedures prior to combat deployments.

Metrics of “success” during recent conflicts include higher survivability rates coupled with greater post-injury quality of life and increased rates of those returned to duty and to previous levels of function and performance. Measurements of the positive impact of CPGs on improved performance, medical care, and research efforts, and reduced outcomes of complications, morbidity, and mortality have provided value to these CPGs and to the organizational structure of a Joint Trauma System that provided a Learning Health System within the Military Health System to ultimately develop and continuously update these CPGs. Notable are burn resuscitation-associated abdominal compartment syndrome mortality decreased from 36% to 18% after introduction of the CPG, hypothermia presentation decreased from 7% to 1% after introduction of the CPG, and mortality in those receiving massive transfusions dramatically reduced from 32% to 20% after introduction of the damage-control resuscitation (DCR) paradigm and its associated CPG. **(Eastridge 2009, Eastridge 2010)**

A review of the scientific literature published during and immediately after a wartime period can be used to evaluate performance improvement and research on a topic (e.g. trauma, combat casualty care), an author (military, civilian), an institution (e.g. Joint Trauma System), and a data source (DoD Trauma Registry, National Trauma Data Bank). The number of citations received by an article can be used to determine the degree of study or article impact or influence on care and changes to CPGs in both civilian and military settings. **(Ollerton 2005, Orman 2012)**

More data is not always the answer

More data does not always automatically translate into useful information. Data must be aggregated and given to the end-user stakeholder in a useable format as has been discussed in the sections on clinical decision support, interoperability and guidelines. However, one other concept that needs to be addressed is the massive proliferation of healthcare data, in particular in the realm of public reporting of quality measures. The United States currently has hundreds of these measures, and at the current growth rate, we will soon be into the thousands. We need to make more rational decisions about our use of data. We need to consider the value of information and only spend money to have data that will be actionable, useful, and will improve care and outcomes for patients. **(Meyer 2012)**

CONCLUSION

Over the past decade, the DoD Joint Trauma System and the DoD Military Health System trauma research program have made great strides toward an integrated approach to a continuous learning health system and evidence-based performance improvement model. Advances in combat trauma care obtained through recent experiences in Afghanistan and Iraq must be solidified and maintained during interwar periods so as to mitigate morbidity and mortality during future conflicts. Knowledge and lessons learned must be translated back and forth between the military's learning health system and the analogous civilian trauma system.

The importance of data driven decision making cannot be overstated. Data and metrics are required for comparative effectiveness research and to adequately perform risk assessments and determine cost-effectiveness of practice changes. Morbidity, mortality, and patient reported outcomes are important measures of system success or failure. Decision support tools can be used to optimize care for all injured patients. Data must continue to be used to inform leaders, and actionable information must be used by leaders to effect system and patient-level changes in care. Clinical practice guidelines must continuously be used, refined, and distributed across trauma systems. Empirical data and evidence-based guidelines more accurately shape education and training; verify and validate education and training curricula; better link education and training with clinical outcomes; and provide a ubiquitous training foundation in basic trauma protocols and procedures. All clinicians in the trauma community must be well-versed in prehospital and hospital guidelines and performance improvement standards. The positive impact of guidelines and other performance improvement efforts can be effectively measured through clinical outcomes. Gaps and barriers to care must be addressed by leaders in order to further improve trauma care and patient outcomes. Currently, there are blind spots in military prehospital medical provider trauma care, both military and civilian prehospital non-medical provider trauma care, and civilian prehospital trauma death analysis. These are areas which can prove most beneficial for improving morbidity and mortality from trauma.

The DoD Joint Trauma System and Trauma Registry is a truly significant recent innovation for military medicine. Continued advancement of military trauma care delivery can be realized through ownership, responsibility, priority, and long-term commitment of institutions and leaders toward data collection and performance improvement at every level of the military trauma system. Data drives system and individual patient requirements, and these needs must be addressed through performance improvement, clinical practice guidelines, training and education, and research and technology. The organizational structure must include appropriate

resources through personnel, training, and equipment that continuously strive to prevent morbidity and mortality and optimize functional recovery, and efforts must be driven by data and science. Research and development, technology and innovation, must receive guidance and priorities from clinical data and outcomes. Current regulations need to be re-examined in order to maximize the benefit of research while concurrently mitigating risk to patients.

No matter which domain is to be considered, the critical common pathway is having data to support any work intended to improve patient care. Data are the backbone required to ensure that attempts at improvement do what they are intended to, rather than having the dreadful unintended consequences that often occur. War is a unique mission of the Military Health System, and war is inevitably associated with trauma. If war has a silver lining, it resides in the potential to advance trauma care to the benefit of civilian lives in addition to military lives. Military medicine must continuously demonstrate ownership and expertise in both prehospital and hospital trauma care, and rapidly integrate and institutionalize lessons learned. An institutional commitment toward eliminating both prehospital and hospital potentially preventable death is a must. Stagnation, interruptions, and "lessons lost" will come at a cost of lives needlessly wasted at the onset of future conflicts. As trauma is a significant part of civilian medicine, translation, relationships, collaboration, and exchange of trauma care best practices must occur continuously between military and civilian sectors - regardless of war or interwar periods.

ACKNOWLEDGEMENTS

The authors would like to recognize the guidance, input, and thoughts as provided by: Karen J. Brasel, MD MPH, Oregon Health and Science University; Eric A. Elster, MD, Uniformed Services University of the Health Sciences; Bari M. Kotwal, MS, Texas A&M Health Science Center Rural and Community Health Institute; Brandyn D. Lau, MPH CPH, Johns Hopkins University School of Medicine; J. Wayne Meredith, MD, Wake Forest School of Medicine; Melanie Neal, American College of Surgeons NTDB and TQIP; Shahid Shafi, MD MPH, Baylor Health Care System Institute for Healthcare Research and Improvement; and Mary Ann Spott, PhD, Department of Defense Joint Trauma System.

APPENDIX I: ACRONYMS

AAAM	Association for the Advancement of Automotive Medicine
AACN	Advanced Automatic Collision Notification
AAST	American Association for the Surgery of Trauma
ACS	American College of Surgeons
ACS-COT	American College of Surgeons-Committee on Trauma
AE	Aeromedical Evacuation
AFMES	Armed Forces Medical Examiner System
AHLTA	Armed Forces Health Longitudinal Technology Application
AIS	Abbreviated Injury Scale
BI	Battle Injuries
CASEVAC	Casualty Evacuation
CCATT	Critical Care Air Transport Team
CDC	Centers for Disease Control and Prevention
CDR	Clinical Data Repository
CENTCOM	Central Command
CER	Comparative Effectiveness Research
CHCS	Composite Health Care System
CHARS	Consortium on the Health and Readiness of Servicewomen
CPG	Clinical Practice Guideline
CIS	Clinical Information System
CLABSI	Central Line-Associated Bloodstream Infection
COCOM	Combatant Command
CONUS	Continental United States
CoTCCC	Committee on Tactical Combat Casualty Care
COTS	Commercial-Off-The-Shelf
CSAR	Combat Search and Rescue
CT	Computed Tomography
DCAS	Defense Casualty Analysis System
DEERS	Defense Enrollment Eligibility Reporting System
DMDC	Defense Manpower Data Center
DNBI	Disease and Non-Battle Injuries
DoD	Department of Defense
DoDTR	Department of Defense Trauma Registry
DOW	Died of Wounds
EAST	Eastern Association for the Surgery of Trauma
EHR	Electronic Health Record
EMS	Emergency Medical Services
FDA	Food and Drug Administration
GCS	Glasgow Coma Scale
HIPAA	Health Insurance Portability and Accountability Act
HHS	Health and Human Services
HL7	Health Level Seven
ICD	International Classification of Diseases
ICD-9	International Classification of Diseases, Version 9
ICD-10-CM	International Classification of Diseases, Clinical Modification, Version 10
ICDPIC	ICD Programs for Injury Categorization
ICU	Intensive Care Unit
IOM	Institute of Medicine
IRB	Institutional Review Board
ISS	Injury Severity Score
JLV	Joint Legacy Viewer

JPTA	Joint Patient Tracking Application
JTAPIC	Joint Trauma Analysis and Prevention of Injuries in Combat
JTS	Joint Trauma System
JTTR	Joint Theater Trauma Registry
JTTS	Joint Theater Trauma System
KDHE	Kansas Department of Health and Environment
KEMSIS	Kansas Emergency Medical Services Information System
KIA	Killed in Action
LHS	Learning Health System
LOINC	Logical Observation Identifiers Names and Codes
LRMC	Landstuhl Regional Medical Center
MCIS	Military Combat Injury Scale
MEDEVAC	Medical Evacuation
MERCuRY	Military En Route Care Registry
MERT	Medical Emergency Response Team
MFIS	Military Functional Incapacity Scale
MHS	Military Health System
MHSSPACS	Military Health System Strategic Partnership American College of Surgeons
MIEMSS	Maryland Institute for Emergency Medical Services Systems
MOTR	Military Orthopedic Trauma Registry
MTF	Medical Treatment Facility
MTOE	Modified Table of Organization and Equipment
MTOS	Major Trauma Outcomes Study
NEMSIS	National Emergency Medical Services Information System
NHRC	Naval Health Research Center
NHTSA	National Highway Traffic Safety Administration
NIH	National Institutes of Health
NISS	New Injury Severity Score
NSCOT	National Study on the Costs and Outcomes of Trauma Care
NTDB	National Trauma Data Bank
NTDS	National Trauma Data Standard
NTI	National Trauma Institute
OASIS	Organization for the Advancement of Structured Information Standards
OCONUS	Outside of Continental United States
OEF	Operation Enduring Freedom
OEMS	Office of Emergency Medical Services
OFS	Operation Freedom's Sentinel
OIF	Operation Iraqi Freedom
OND	Operation New Dawn
PAD	Patient Administration
PASBA	Patient Administration Systems and Biostatistics Activity
PCORI	Patient Centered Outcomes Research Institute
PCR	Patient Care Record
PHTLS	Prehospital Trauma Life Support
RDT&E	Research, Development, Test, and Evaluation
RHIA	Registered Health Information Administrator
RHIT	Registered Health Information Technician
RR	Respiratory Rate
RTD	Returned to Duty
RTS	Revised Trauma Score
SBP	Systolic Blood Pressure
SDO	Standards Development Organization
SNOMEDCT	Systematized Nomenclature of Medicine - Clinical Terms
SRR	Survival Rate Ratio
TAC	Technical Assistance Center

TBI	Traumatic Brain Injury
TCCC	Tactical Combat Casualty Care
TDA	Table of Distribution and Allowances
TIDOS	Trauma Infectious Disease Outcome Study
TMDS	Theater Medical Data Store
TMPM	Trauma Mortality Prediction Model
TQIP	Trauma Quality Improvement Program
$TRAC^2ES$	TRANSCOM Regulating and Command and Control Evacuation System
TRANSCOM	Transportation Command
TRIP	Translating Research (Evidence) into Practice
TRISS	Trauma Score - Injury Severity Score
USAISR	United States Army Institute of Surgical Research
USSOCOM	U.S. Special Operations Command
USUHS	Uniformed Services University of the Health Sciences
VA	Veterans Affairs
VistA	Veterans Health Information Systems and Technology Architecture
VOI	Value of Information
WDMET	Wound Data and Munitions Effectiveness Team
WHO	World Health Organization
WIA	Wounded in Action
WISPR	Web Interface for Scanned Patient Records
WISQARS	Web-based Injury Statistics Query and Reporting System
XML	Extensible Markup Language

APPENDIX II: INJURY SEVERITY SCORING SYSTEMS

One of the earliest systems to code anatomic scoring was proposed by the Association for the Advancement of Automotive Medicine (AAAM). Their Abbreviated Injury Scale (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 6-point ordinal scale." (**AAAM 2015**) These underlying AIS scores can be combined into a composite anatomic injury score for the multiple injured patient, known as the Injury Severity Score (ISS) first published by Sue Baker in 1974 and still used in the same form today. (**Baker 1974**) The ISS is an ordinal scale with ranging from 1 to 75. More recently, the New Injury Severity Score (NISS) has been suggested to overcome known limitations of the ISS which underappreciates multiple injuries in the same body region (**Lavoie 2004**) and does not work well for patients with penetrating injury. (**Smith 2015**) Unlike the ISS, the NISS considers the three most severe injuries, regardless of body region.

The ISS is also an imperfect tool for controlling for case mix in combat injury, as it may underestimate complex battlefield wounds, and even more so is limited by the originally defined civilian AIS codes upon which it is based. Thus, a group of military surgeons convened to create AIS 2005-Military (AIS 2005.mil, since updated to AIS 2008.mil) in an effort to compensate for the inability to code large soft-tissue and complex multisystem injuries. (**Champion 2010**) Although some improvement was realized with these initial military scoring tools, they were still inadequate, as they did not completely describe and appropriately assign severity to combat injuries, which prompted the creation of the Military Combat Injury Scale (MCIS) and the Military Functional Incapacity Scale (MFIS) in 2013. (**Lawnick 2013**) The MCIS and MFIS were developed by a large group of military and civilian combat trauma subject matter experts. The MCIS is simple to use with only 269 codes, and it has been extensively validated on combat data. The MCIS severity levels were based on urgency, care needed, and risk of death from each separate injury. The MFIS was based on a casualty's ability to "shoot, move, and communicate" as required by military combat missions.

In addition to the well-accepted premise that anatomic injury must be accounted for, clinical trauma providers also appreciate the varying physiologic derangement of injured patients with similar anatomic injury patterns. This recognition led to the development of physiology based trauma scores such as the Revised Trauma Score (RTS). The RTS is a pure physiological scoring system, calculated using the first set of patient data obtained and consists of Glasgow Coma Scale (GCS), Systolic Blood Pressure (SBP) and Respiratory Rate (RR). (**Champion 1981**) The anatomic ISS can be combined with the physiologic RTS and to derive a probability of survival known as the Trauma Score – Injury Severity Score (TRISS). (**Champion 1981, Boyd 1987**) The coefficients for the TRISS formula were originally derived from the MTOS study cohort.

Numerous other trauma scoring systems have been created, often in an attempt to quantify injury severity from limited data sources (i.e. administrative billing data) that do not have specific variables to calculate ISS, RTS, or TRISS. The ICD Programs for Injury Categorization (ICDPIC) were designed to translate International Classification of Diseases Ninth Revision (ICD-9) diagnosis codes into standard injury categories and/or scores. (**Clarke**) Other approaches include the Barell Matrix category (**Barell 2002**), the Survival Rate Ratio (SRR) **(Rutledge 1997**), and the Trauma Mortality Prediction Model (TMPM). (**Osler 2008**)

APPENDIX III

CASE REPORT: THE OPTIMAL USE OF DATA ACROSS THE CONTINUUM OF CARE

This real-life case exemplifies how data could be used to improve care of a severely injured military service member. Through optimized data sharing and clinical decision support, the service member receives optimal, timely trauma care along a continuum of multiple levels of medical capability across three continents. *Everything shown in italics is currently feasible from an information technology and electronics perspective, although not all systems are currently implemented in practice.*

CARE UNDER FIRE

A 29-year-old male service member sustains a gunshot wound (GSW) to the head while on patrol following a .50 caliber sniper rifle projectile penetration of the right side of his helmet. A nonmedical but first-responder-trained member of his squad immediately assesses the opportunity for bleeding control, moves the casualty to a hasty casualty collection point (CCP) with cover and concealment, and notifies the squad leader of the casualty and his injury. The squad leader immediately contacts the platoon sergeant, who directs his platoon medic to the casualty to provide additional care.

TACTICAL FIELD CARE

On arrival, the medic opens his tablet and establishes a linkage with the appropriate medical command center (MCC). At the MCC, a "smart map" identifies and displays the location of the call. An emergency medical communicator (EMC) instructs the medic to identify the potential patient, conduct a primary assessment, convey a "MIST" report (Mechanism of Injury, Injury, Signs/Symptoms, Treatments), and initiate a request for urgent transport and links this information stream to the patient's existing medical database identifiers in the MCC computer.

At the CCP, the patient is noted to have strong carotid pulses, a heart rate (HR) of 130 beats per minute (bpm), and a respiratory rate (RR) of 75 breaths per minute. He is unresponsive and exhibits decorticate posturing. *In the meantime, the "smart map" has identified and dispatched the closest acute care response vehicle to the patient. Patient information is linked to an existing health care record, giving the medic access to the patient's health care database, current health problem list, current medications, allergies, and blood type. As patient care information is collected, it is automatically copied to the responding ground medic's patient care record, to the responding transport medic's patient care record, to the closest Role 2 military treatment facility (MTF), to the closest Role 3 MTF, and to the MCC. A real-time clinical decision support tool prompts the field medic to control the patient's airway because of his depressed Glasgow Coma Scale score.* A cricothyroidotomy is performed, and the casualty is placed on a mini-ventilator. The casualty is wrapped in a hypothermia prevention management kit, *and an electronic tactical combat casualty care (TCCC) card is completed and transmitted.*

TACTICAL EVACUATION

An air transport vehicle arrives within 5 minutes of the evacuation request. *The flight paramedic has received and reviewed all patient care documentation prior to arrival.* A Role 2 MTF is located 45 minutes away, and a Role 3 MTF with a neurosurgeon is located 60 minutes away. *Based on his decision support matrix, the flight paramedic directs the pilots to fly to the Role 3 MTF,* provides supplemental oxygen to the casualty, and attaches *an all-systems monitor to the casualty's arm and across his chest. Physiologic data are acquired by the monitor's computer chip, then analyzed on the scene and transmitted to the medic's tablet and the MCC collocated with the Role 3 MTF. The flight medics are able to acquire the patient's medical history electronically and treat accordingly.*

Through the medic's tablet, a video connection is established with the Role 3 MTF and MCC. An MCC emergency medical services (EMS) physician views the patient and his associated vital signs and requests additional Level III monitoring. The patient's vital signs are blood pressure (BP) 80 mmHg (systolic only), HR 135 bpm, RR 30, Glasgow Coma Score (GCS) 3, and oxygen saturation (SpO2) 95 percent. His right pupil is measured at 3 mm and reactive. His left pupil is measured at 4 mm and also reactive. The patient exhibits decorticate posturing. His head wound dressing rapidly becomes soaked with blood. *Analysis of all the data and active surveillance of decision support tools by the MCC computer and EMS physician* lead to dosing with tranexamic acid, transfusion of 2 units of red blood cells (RBCs), and infusion of 3 percent hypertonic NaCl en route. Ventilation is maintained by mini-vent, and SpO2 is sustained at 100 percent. *An electronic tactical evacuation patient care record is completed and transmitted. The receiving MTF has received all patient vitals and physical exam and care documentation before the patient's arrival. Accordingly, personnel at the MTF plan for a very briefly emergency department assessment, empty the computed tomography (CT) scanner, and prepare a surgical suite with a waiting neurosurgeon.*

RECEIVING ROLE 3 MILITARY TREATMENT FACILITY

Upon arrival at the Role 3 MTF, the patient is noted to have the following vital signs: BP 153/108 mmHg, HR 69 bpm, RR set by ventilator, rectal temperature (T) 99.8°F, and GCS 3T. A cervical spine collar placed on the patient prior to arrival *is rapidly removed in accordance with an evidence-based clinical practice guideline that summarizes the medical literature on the topic*. A CT scan reveals a GSW to the head at the vertex of the skull with displacement of multiple bone fragments and evidence of diffuse cerebral edema, intraparenchymal hematoma, subarachnoid hemorrhage (SAH), subdural hemorrhage (SDH), and epidural hemorrhage (EDH) at the vertex in association with disruption of the mid third superior sagittal sinus.

The patient is taken to the operating room for decompressive hemi-craniectomy, evacuation of subdural hematoma, placement of a right-sided external ventricular drain (EVD), and switch from a 7.5F field cricothyroidotomy tube to placement of an 8.0F tracheostomy. His postoperative CT reveals postsurgical changes, enlargement of right frontal lobe parenchymal hematoma, bilateral enlargement of the lateral ventricular horns, effacement of all basal cisterns, persistent subarachnoid and parafalcine SDH, a 3-4 mm midline shift rightward, multiple bone fragments within the brain parenchyma, and extensive scalp edema. He is administered thyroxin on a standard T4 protocol, as well as 3 percent NaCl. A second EVD is placed on the left side because of increasing bifrontal cerebral hemorrhaging reflected in an intracranial pressure (ICP)

measurement of 23 mmHg. Following this intervention, ICP improves to 8-10 cmH20 and a cerebral perfusion pressure (CPP) of 60 mmHg. Repeat CT shows transcranial herniation at the site of the craniectomy with evidence of impending tonsillar and uncal herniation, as well as a small amount of right subfalcine herniation. The patient is transfused 2 units of RBCs, 2 units of fresh frozen plasma (FFP), and 1 unit of apheresis platelets. Tranexamic acid is also infused in an effort to control bleeding. Ultimately, the patient's GCS improves to 7T, with a motor score of 4. He undergoes bronchoscopy to evaluate the effects of the surgical airway procedures and is found to have no evidence of tracheal injury. *All medical charting is completed electronically during the patient's stay and automatically uploaded to the MCC computer. An abbreviated medical status report is exported to the critical care air transport team's tablet for use during transport care.*

CRITICAL CARE AIR TRANSPORT TEAM: MOVEMENT OUT OF THEATER (POSTINJURY DAY #1)

The patient is transported to the flight line without incident. Sedation is increased prior to transport, resulting in a drop in GCS from 6T to GCS 3T. *Tele-ICU monitoring is initiated and monitored by a Role 4 MTF. Answers to questions raised by the Tele-ICU team are provided instantaneously and care is modified based on those recommendations.* In flight, CPP is maintained at greater than 60 mmHg with low dose vasopressors, and ICP is maintained at less than 20 mmHg. The patient is transfused 2 units of RBCs and a 300 ml bolus of normal saline (NS). His hemoglobin increases from 8.2 to 9.2 g/dL. *All patient care data collected during the flight are automatically uploaded to the MCC computer. Ventilation is provided via closed-loop ventilation that automatically adjusts the inspired oxygen content and RR in response to changes in oxygenation and end-tidal carbon dioxide monitoring.* Upon arrival at Landstuhl Regional Medical Center in Germany, GCS has returned to 6T.

ROLE 4 MILITARY TREATMENT FACILITY: GERMANY (ARRIVAL POSTINJURY DAY #1)

The patient is hemodynamically stable on arrival and is rapidly weaned off vasopressors. His GCS is initially 5T, with ICP of less than 20 mmHg; brainstem reflexes are intact. He is evaluated by a neurosurgeon, and a repeat CT is performed. The CT reveals intraventricular and large intraparenchymal hemorrhages. His ICP gradually increases to greater than 20 mmHg, and he is taken back to the operating room for evacuation of hematomas and drain placement. ICP improves, and GCS post-op is 4T. Enteral feeding is begun. Prophylaxis for *deep venous thrombosis (DVT) and pulmonary embolism (PE) is begun early based on a personalized medicine approach utilizing the patient's demographics, thromboelastography data, and precision genomics.* Baseline duplex ultrasound of the extremities reveals no thrombi.

All medical charting is completed electronically during the patient's stay and automatically uploaded to the MCC computer. An abbreviated medical status report is exported to the flight care team's tablet for use during transport care. The patient is evacuated to the United States with a GCS of 4T. The flight is uneventful.

ROLE 5 MILITARY TREATMENT FACILITY: UNITED STATES

The initial care team in the United States has full access to the patient's past and current care medical record, including CT images and intraoperative photographs, through the MCC. A patient care conference is held days before the patient arrives, and care plans are prepared and initiated upon his arrival. The patient is hemodynamically stable on admission, *but transport trend vital signs suggest a slight but growing fever.* The infectious diseases service is available upon the patient's arrival, and its evaluation reveals pneumonia with a focus in the right lower lobe. Organisms isolated include *Hemolytic streptococcus* and *Serratia rubidaea*. The patient is administered antibiotics and antifungals. His GCS improves to 5T and ICP remains within normal range. His anasarca and brain edema improve, and he is able to tolerate enteric feeding.

The patient is transitioned to emerging consciousness rehabilitation after removal of the ventriculostomies on postinjury day 35. His pneumonia has resolved. Long-term follow-up demonstrates dramatically improved mental status. The patient can communicate reliably and is fully oriented. He does exhibit several cognitive deficits, such as reduced attention span and ability to concentrate, reduced visual spatial skills, and left-sided neglect, as well as some memory impairment. His physical status has also improved. He is able to use his right upper extremity and has modest antigravity strength in his right lower extremity. He has little use of his left upper or lower extremities as a result of the site of brain injury. He tolerates sitting for greater than 4 hours per day and can stand for 40 minutes at a time. His tracheostomy is decannulated and he can eat a regular diet.

This case represents an appropriate use of a learning health system to ensure seamless transitions of care between care teams, resulting in the best possible outcome for a severely injured patient.

APPENDIX IV: ENHANCING DATA USABILITY

This appendix highlights methods to link independent datasets, enhance data interoperability and reduce the effect of missing or inaccurate data.

Methods for Integrating Data from Independent Sources

Clinical information in the civilian sector is fragmented across independent databases. This makes evaluating patient care and systems of care nearly "unmanageable". Much time and effort has been expended attempting to develop after-the-fact methods to link independent data sources. Many applications designed to "link" independently collected datasets address the fact that existing collection efforts are not designed for linkage (**Clark 2004**). Issues that must be addressed include; data set quality, coverage, schema consistency, quality control and timeliness. A cursory discussion of available techniques is provided below:

1. *Deterministic linkage*: A direct case matching approach that relies on the existence of the same tangible individual identifiers being present in each of the independent data sets to be linked. Examples would include; name, home address, birthdate and, social security number. When using a deterministic record linkage procedure, two records within disparate databases are considered to match if all or some identifiers above a certain statistical threshold are identical. Deterministic methods commonly utilize "rule-based or "heuristic-based" decision algorithms and are highly dependent on the quality and intrinsic discriminability of the elements common to the independent datasets. As an example, a measure of sex in both datasets may be considered valid and reliable, but will provide little discriminability among records (i.e., many datasets include males and females at about 50:50 ratio). First name may be considered to have a higher level of discriminability but precision may be a problem (i.e., the first name "Robert" in one dataset may be listed as Bob, Robby, Bert, Rob in another dataset.
2. *Fuzzy match linkage*: Another direct case matching approach (i.e., based upon exact match agreement) that expects (allows for) errors to be present in (and between) the underlying individual datasets. For example, when matching records related to infants in different datasets, a rule may be included in this approach that allows age to vary by +/- 30 days between the datasets and still be considered a potential match. Many string comparators and phonetic transformation functions have been introduced to allow for matches among common language variations. For example, mentioned earlier, the first name "Robert" may be linked to Bob, Bobby, Rob, etc.
3. *Probabilistic linkage*: A method specifically designed to address linkage among datasets when few (or no) unique person identifiers are available among the datasets considered for linkage (**Dean 2001**). The process relies on a wider range of potential "semi-identifiers" and computes weights for each identifier based on its estimated ability to correctly identify a match or a non-match. These weights are combined across many assessed elements within the datasets to calculate the probability that two given records refer to the same entity. Record pairs across the datasets with probabilities above a certain statistical threshold are considered matches, record pairs with probabilities below a threshold are considered non-matches; and those in between the two thresholds are considered "possible matches". As an example, among health records, a match between

two records in different datasets on sex would receive a lesser weight than a match on diagnosis.

4. *Machine Learning Models:* Assorted methods that rely on iterative mixture models that can be used to partition record pairs into two or more groups that can be labeled as probable matches (links) and probable non-matches (non-links). (**Sauleau 2005**). In general, these methods rely on the calculation of a conditional probability of a match and "group" potential matches using an assortment of techniques including clustering, decision trees and vector machines. For the most part, these techniques outperform traditional probabilistic approaches and naïve Bayes classifiers.

Data Semantics and Nomenclature

Data exchange between multiple independent systems is only possible if all systems have universally accepted common standards for data structure, content and exchange. Data standards provide a consistent meaning to data shared among different information systems. Attributes of data element standards include; representation, format, definition, structuring, tagging, transmission, manipulation, use and management. As an example, terminology and element structure standards control the terms and definitions used to represent information and aid in exchange and interpretation of data. These standards commonly include:

1. Element structure – can elements recur; are elements mandatory or optional; are null or NOT values allowed; will pertinent negatives be used; can an element be left blank?
2. Element naming conventions – are elements hierarchical; what naming/numbering conventions will be used; are elements bundled based upon a purpose (i.e., medication administration)?
3. Element definitions – are there existing national (or international) standard definitions for some elements; are there secondary definitions, exclusions or additional information that must be provided to add clarity?
4. Element code sets – Are element values a closed set, open-ended, or limited based upon a pattern (e.g., ICD-10-CM); are codes listed sequentially or alphabetical; do code sets reference external standards?
5. Element relationships – are some elements nested under other elements; should groups of elements be repeatable?

The use of data structure and nomenclature standards facilitates the exchange of data among disparate users. A number of national (and international) standards exist to ensure a shared understanding of a specific domain of codified data. Examples include:

1. LOINC - Logical Observation Identifiers Names and Codes, a database and universal standard for identifying medical laboratory observations.
2. SNOMED CT- Systematized Nomenclature of Medicine - Clinical Terms, a standardized, multilingual vocabulary of clinical terminology that is used by physicians.
3. RxNorm – a structured organization of standard names given to clinical drugs and drug delivery devices used in the United States.
4. ICD-10 - International Statistical Classification of Diseases and Related Health Problems, a medical classification of diagnoses and procedures.

Organizations exist that ensure national (and international) data exchange standards are correctly applied in information systems designed to send or receive data from external sources. These Standards Development Organizations (SDOs) provide a platform to introduce, structure and vet a novel information exchange process, ensuring that your efforts are harmonized with similar or complementary data systems in existence. SDOs associated with health public safety related standards include Health level Seven (HL7) and the Organization for the Advancement of Structured Information Standards (OASIS).

Issues Associated with Missing Data

Missing values are an all-to-often occurrence in databases. The negative consequences resulting from missing data cannot be overstated and nearly always significantly impact the conclusions that can be drawn from use of the affected database. A reliable prescriptive approach to minimizing the consequences of missing data is to ensure a well-structured dataset (i.e., prohibit null ["blank"] values where possible) and utilize "close call" business rules that require informants to provide a valid value for each element. Nevertheless, missing data will occur and methods have been devised to mitigate the effects. In essence, most of these methods replace a missing value with a "best guess" value based upon varied mathematical approaches to maximize the probability of a correct guess. It should be noted that, even among statisticians, there is polarization regarding whether these methods should be utilized at all. This disagreement exists, in part, because it can be very difficult to test the assumptions that underlie many techniques using most available databases.

When considering application of techniques to deal with missing data, it is important to understand "how" data are missing. There are three types of missing data:

1. *Missing completely at random:* The assumption that missing data occurs independent of both observable and unobservable factors that could have resulted in the element being left blank. That is to say, there are no known (or unknown) reasons explaining why the element was reported as missing. If, in fact, this assumption is true, missing data in the dataset will not bias any analyses that are performed using the data. As one might surmise, testing this assumption is, for most purposes, impossible.
2. *Missing at random:* The assumption is that "missingness" is not "completely" at random, and that existing (and available) data elements, can be used to account for information that is missing. It is likely that this assumption cannot be tested, using the available information, but may be assumed based upon some assertion of reasonableness.
3. *Not missing at random*: The assumption is that even accounting for all of the information that is available within a dataset, reasons that elements are missing depend on factors that yet remain unknown.

Methods to Address Missing Data

What can be inferred from the information above is that most techniques devised to deal with "missingness" in datasets focus on the issue of data *missing at random.* Proposed techniques range from simply removing targeted elements or cases to devising complex method of modeling "predictions" for missing values. A brief description of common techniques are listed below:

1. *Element deletion*: An approach to missing data, particularly if the amount of missing values within a given element is large, is to simply remove (i.e., censor) that element from the analysis.
2. *Listwise deletion*: A more extreme censoring technique involves eliminating subjects from the analysis for which information is missing. That is, if a subject is missing data for any of the elements used in an analysis, the case (i.e., subject) is dropped for that analysis. This approach is often used when the amount of missing data is small. Nevertheless, it is important to remember that the remaining subjects may not be representative of the larger population and if other analyses are done, with the same dataset but different samples, the findings of the two investigations may not be comparable. This technique is often associated with multivariate regression modeling since several regression techniques require the removal of cases with missing values.
3. *Missing data indicator*: An ill-advised, but related, approach to missing data is to incorporate an unobtainable value into an element to represent missing data (e.g., "001" for a missing systolic blood pressure value). This approach allows subjects (and elements) to remain in analyses, but may systematically bias the findings if the statistical approach interprets the value as valid. Also, similar to the techniques mentioned thus far, this technique does nothing to approximate the information that is missing.
4. *Single imputation*: A commonly used strategy when the amount of missing values is large, is to substitute some plausible guess for the missing values. A common simple imputation is to insert the overall mean value based upon among available values to replace all missing values for that element. It is also common to compute a subgroup mean (e.g., mean among males) as a replacement value in an attempt to increase the likelihood that a substitution value will approximate the truth, in this example, for males. Taken further, multivariate regression modeling may be performed to further increase the likelihood that a substitution value may approximate the truth, by imposing the influence (i.e., explained variance) of many other known elements on the estimate.
5. *Multiple imputation*: In essence, multiple imputation involves "estimating" missing entries, as was done in simple imputation, many times using a distribution of plausible values, resulting in many complete datasets. Each of these datasets are analyzed and the results are pooled to provide the best guess for each missing value (**Oyetunji 2011, Newgard 2012**).
6. *Matching or (hot deck) imputation*: A modification on multiple imputation is to begin the process by "matching" each missing value with an available value from a "similar" subject, as a starting point, and then develop multiple complete datasets for use in a multiple imputation process (**Fuller 2005**).
7. *Last observation carried forward*: Under rare circumstances, a subject may have a previous recorded (and available) value that is similar to the missing value (e.g., a previous blood pressure measurement). In this case, the prior value often serves as the "best guess" for the missing value.
8. *Interpolation models*: Methods by which patterns, cycles or trends present among available values are used to interpolate the probable value for missing data present in elements that would be influenced by the identified pattern or trend (**Little 2002**).
9. *Iterative algorithms*: These techniques often utilize naive or informed training subsets of data to iteratively discover the relationships between available and missing data to inform the decision when estimating missing data (**Little 2002).**

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