Current Problems in Surgery 58 (2021) 100849

Contents lists available at ScienceDirect

Current Problems in Surgery

journal homepage: www.elsevier.com/locate/cpsurg

The impact of trauma systems on patient outcomes

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The burden of trauma

Trauma is a pressing public health epidemic. In 2016 alone, trauma accounted for 29.2 million emergency department visits and 39.5 million physician office visits in the United States.[1] Trauma is the leading cause of death for those aged 46 years and younger in the United States; trauma-related mortality has increased by 23% between 2000 and 2010 across nearly all age groups.[2] In particular, the growing elderly population—susceptible to injuries from even minor mechanisms such as ground-level falls—has seen a 56% increase in trauma-related deaths over the same decade.[2] For those who survive, regaining health and returning to work requires substantial postacute care and rehabilitation. Accounting for medical expenditures and lost productivity, the annual burden of trauma care is approximately $670 billion in the United States.[3] Traumatic injuries also remain an important cause of morbidity and mortality globally, for both developed and developing countries. In a recent update to the Global Burden of Disease study—the most comprehensive epidemiological study to date—973 million individual healthcare encounters and 4.8 million deaths were attributable to injuries in 2013 alone.[4]

The recognition of traumatic injuries as an addressable public health epidemic rather than unavoidable accidents has led to the birth and expansion of trauma systems. Trauma systems represent comprehensive infrastructures to provide optimal care for injured patients, encompassing a wide spectrum from injury prevention efforts and an integrated network of trauma centers to concerted research agendas. The United States has led the development of this systematic infrastructure to tackle the burden of trauma. In this report, we review the history of trauma systems in the United States, outline what constitutes a comprehensive trauma system,

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https://doi.org/10.1016/j.cpsurg.2020.100849

provide an overview of trauma systems in other countries, and explore the cumulative impact of trauma systems on the outcomes of patients who suffer traumatic injuries.

History of trauma systems in the United States

Military roots

A structured system to care for the injured arose amidst the chaos of military conflicts. The American Civil War gave birth to the medical evacuation system, which was comprised of an ambulance corps and placing of surgeons near battlefields to determine who could return to battle or be transferred to field hospitals.[5] The mass casualties of World War I propagated triage through tiered echelons of increasingly capable treatment.[6] Adoption of motorized transportation for evacuation (ie, helicopters in the Korean War) spurred more expeditious evacuation throughout subsequent conflicts. By one estimate, the average injury-to-surgery time progressively improved and mortality progressively decreased from 12 to 18 hours and 8.5% (World War I), to 6 to 12 hours and 5.8% (World War II), 2 to 4 hours and 2.4% (Korean War), and 65 minutes and 1.7% (Vietnam War), respectively.[7]

First national spotlight

While systematic care for the injured took early roots in the military, the need for a structured trauma system did not receive civilian spotlight until the publication of "Accidental Death and Disability: The Neglected Disease of Modern Society" in 1966.[8] This landmark report highlighted accidental injury as a neglected epidemic and the "leading cause of death in the first half of life's span."[8] The report underscored our country's deficient emergency medical care capacity and urged the establishment of trauma registries, hospital trauma committees, and increased funding for trauma research.[8] The same year, the federal government launched the first national effort to care for injured patients through "The National Traffic and Motor Vehicle Safety Act."[9] The mandate of vehicle standards (eg, seatbelts), improved road standards, and public education of driver safety laws (eg, laws against driving while intoxicated) led to a rapid decrease in motor vehicle fatalities by 1970, showcasing traumatic injuries to be a preventable epidemic.[10]

With the national spotlight on injury, local leaders advancing trauma systems emerged. The Cook County Hospital in Chicago consolidated care of all trauma patients and developed a dedicated trauma team unit, gaining recognition as one of the nation's first trauma centers in 1966.[11] At a similar time, University of Maryland Hospital established its shock trauma unit and popularized the "golden hour" for trauma resuscitation. In collaboration with Maryland State Police, the shock trauma unit birthed the Maryland Institute for Emergency Medical Services System. This collaboration reduced trauma-related mortality by transporting critically injured patients from the field or regional hospitals via police helicopters to a dedicated trauma unit.[12] Although not as well-recognized, the first "trauma center" may have been established at the University of Louisville. In 1911, Dr William O Roberts (Chair of the Department of Surgery) assigned 4 University of Louisville medical students to be on hand at all times to provide accident victims with instant attention. In the 1930s and 1940s, Dr R Arnold Griswold (Chair of the Department of Surgery) developed autotransfusion, established Louisville's first blood bank, and equipped police cars and fire trucks with medical supplies. This was the forerunner of emergency medical services (EMS).[13]

Trauma Center to Trauma System

The "Emergency Medical Services Systems Act of 1973" allocated the first federal funds to establish EMS systems.[14] Illinois became the first state to receive a $4 million federal grant to

build upon Cook County Hospital's trauma center and establish a statewide trauma system with 40 integrated trauma centers.[15] The Illinois trauma system also instituted the first trauma registry, a dedicated database to document and monitor care delivered to trauma patients. Over the next 8 years, $300 million in federal grants helped establish 304 EMS regions throughout the United States.

In 1976, the American College of Surgeons "Optimal Hospital Resources for Care of the Injured Patient" report detailed what constitutes a trauma center and presented a method to designate trauma center levels based on capabilities.[16] This classification—now ranging from level I (tertiary center with 24-hour capability for definitive trauma care) to level IV/V (centers limited to initial evaluation/stabilization prior to transfer)—mirrored the tiered echelons of increasing treatment capacity conceptualized earlier in the military. Subsequent revisions expanded in scope to emphasize the need to care for the injured in the prehospital setting. There was growing recognition that optimal care of the critically injured mandates not only advancement of trauma centers, but also their integration within a comprehensive trauma system.

Developing trauma systems has not been without challenges. The "Omnibus Budget Reconciliation Act of 1981" ended federal government support of EMS due to budgetary constraints.[17] In a 20-year follow-up to the 1966 landmark report, "Injury in America: A continuing Public Health Problem" elucidated persistent deficiencies in coordinated trauma systems and lack of trauma research funding in the United States.[18] A 1995 report similarly found that only 20 states had adopted trauma systems, only 5 of which were fully functional.[19] The following section details components of a comprehensive trauma system that we are still striving for.

The comprehensive trauma system

Components

The modern comprehensive trauma system optimizes cost-effective and high-quality care of the injured patient starting with injury recognition, triage to an appropriate trauma center, multidisciplinary inpatient care, and outpatient follow-up of long-term physical and psychosocial sequelae. Beyond the clinical care continuum, a trauma system also prioritizes outreach, education and advocacy, data collection through registries, research, funding, and disaster preparedness and response. Coordination of comprehensive trauma care requires strong leadership and community engagement at the trauma center, regional, state, and national levels (Fig. 1).

Leadership—American College of Surgeons Committee on Trauma

Since its inception in 1922, the American College of Surgeons Committee on Trauma (ACS COT) has been integral in leading US trauma system development. ACS COT provides trauma center verification and assessment of regional trauma systems and resources to support quality improvement.[20] Within the ACS COT, the Verification Review Committee (VRC) performs on-site review of trauma centers.[21] The ACS COT has spearheaded trauma education by offering courses such as Advanced Trauma and Life Support (ATLS) and Advanced Surgical Skills for Exposure in Trauma (ASSET). The ASC COT has also supported quality improvement through data collection and benchmarking using the National Trauma Data Bank (NTDB) and the Trauma Quality Improvement Program (TQIP). In conjunction with the American Association for the Surgery of Trauma, the Eastern Association for the Surgery of Trauma, the National Trauma Institute, and the Western Trauma Association, ACS COT helped establish the Coalition for National Trauma Research (CNTR) to advance trauma research. The coalition addresses gaps in trauma research (eg, resuscitation, regenerative medicine, family support following major trauma) with plans to update a national trauma research repository and formalize a national trauma research agenda.

Federal legislative advocacy is another effort led by the ACS COT. The committee's efforts have contributed to the successful passage of legislation, including 1 bill that provides

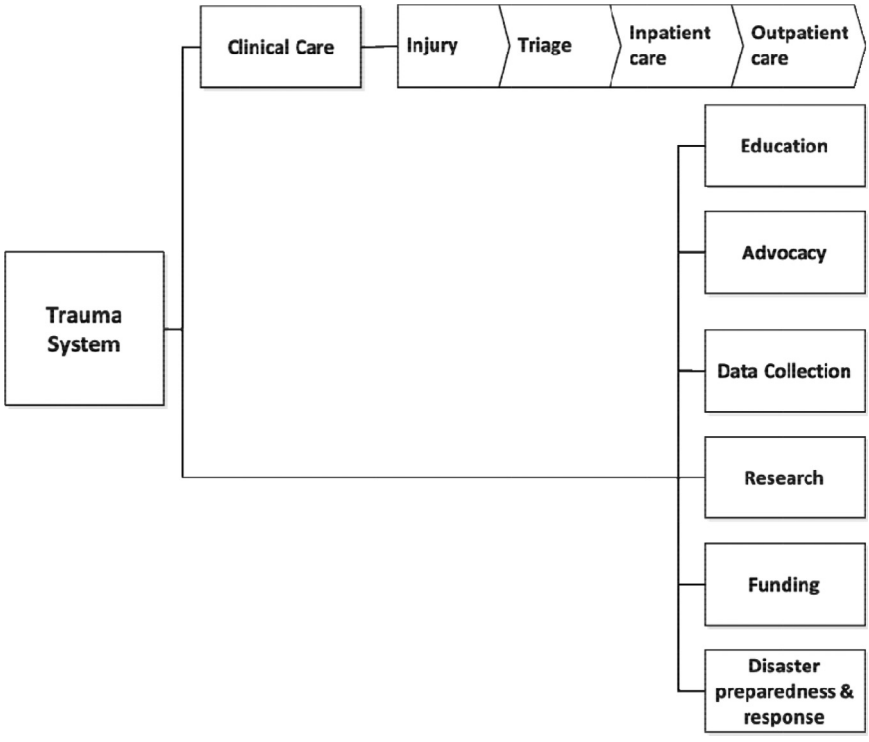

Fig. 1. Components of a comprehensive trauma system.

$50 million of funding for firearm morbidity and mortality prevention research and the MISSION ZERO Act that funds the embedding of military trauma professionals within civilian trauma centers to promote military-civilian collaborations. Ongoing advocacy efforts include support of the Prevent Bleeding Loss with Emergency Devices (BLEEDing) Act to teach civilians life-saving skills via bleeding control techniques and promoting nonpartisan public health approach to firearm injury prevention.

Needs based assessment

There are more than 500 designated and verified level I-III trauma centers currently in the United States tasked with providing timely care of patients who suffer traumatic injuries.[22] Hospitals may request trauma center designation by the governing body, which varies state by state, then receive verification from the ACS COT's VRC. For example, whereas California trauma center designation is determined by local EMS agencies, Alabama and Georgia trauma centers receive designation through their respective Departments of Public Health.[23-25] Notably, some states have no formal process or laws giving authority for trauma designation. Funding for trauma systems is also dependent on the state, but some trauma systems receive no state funding.[26]

Interstate variability of trauma systems has resulted in suboptimal distribution of trauma centers. A 2003 report found that despite a doubling of the number of trauma centers between 1991 and 2002, the number of level I and II trauma centers per million population varied from 0.19 to 7.8 by state.[27] A recent study similarly revealed nonuniform access to trauma care in the United States, with lower injury mortality rates in states that had a clustering of trauma centers compared to states with dispersed trauma centers.[28] In 2015, the ACS COT developed the Needs

Based Assessment of Trauma Systems (NBATS) tool to determine the number of trauma centers per level designation needed in a region based on injury volume, accessibility, and population characteristics.[29] The tool is applied to preexisting trauma regions of interest and incorporates community support, population, transport time, and the number of severely injured patients discharged from non-level I-III trauma center hospitals.[29] The algorithm outputs an estimate of the number of levels I, II, and III trauma centers needed for the region. Application of the NBATS tool to California and Georgia state trauma systems found that urban areas had proportionally too many, and rural areas too few trauma centers.[30,31] A similar optimization query in Florida showed that adding 2 new trauma centers did not improve the state trauma system triage performance, while a Pennsylvania study found that a rural hospital incorporation into the state system as a level IV center would improve performance.[32,33] An increasing number of states are integrating level V trauma centers within their trauma systems. NBATS is continually utilized to assess trauma center needs and direct growth within trauma regions. Although level V designation is not formally recognized by ACS COT, these hospitals are often located in rural areas and focus on high-quality patient stabilization and strong transfer protocols to more comprehensive trauma centers. For example, Washington has integrated 9 level V trauma centers as of January 2020.[34] The optimal trauma system depends not only on a sufficient quantity of trauma centers, but also on a strategically distributed cohort based upon regional needs.

Training programs

ACS COT and partner organizations engage in multiple educational efforts. ATLS is a premier example. ATLS was established in 1978 by Dr James K. Styner, an orthopedic surgeon who attributed the loss of his entire family to sub-par trauma care at a local hospital after a tragic plane crash.[35] Along with a local group of surgeons and physicians and the University of Nebraska, Dr Styner founded systematic courses aimed at teaching advanced trauma life support skills. Since these courses were adopted by ACS COT in 1980, ATLS is now taught in more than 80 countries and has trained more than 1 million physicians.[36] ATLS is comprised of a manual, standardized lectures, and skills stations. Certification requires passing a written component and successfully assessing and resuscitating multiple injured patients in a series of role-playing scenarios. The global audience of the program has increased the standardization of care for the critically injuries patient. Retrospective studies comparing mortality in the pre-ATLS vs post-ATLS eras have shown a 20% reduction at one large international institution and a statistically significant reduction in mortality within the first hour at 2 US community hospitals.[37,38] Since 2009, the American Board of Surgery has required ATLS certification for general surgery residency graduates.

Educational infrastructures allow widespread dissemination of new trauma training curricula. For example, focused assessment with sonography for trauma (FAST)—a bedside ultrasonography technique to assess the presence of blood around the heart or abdominal organs after trauma—was a new skill-based technology disseminated rapidly through the ATLS training curriculum.[39] After the first description of ultrasound to detect intraabdominal fluid in Europe during the 1970s, FAST was formalized as a standardized series of steps and adopted in the United States in the 1990s.[40] Today, 96% of level I trauma centers report regular use of FAST for the assessment of trauma patients.[41,42]

Since its introduction of ATLS, ACS COT's repertoire of educational initiatives has expanded. Trauma Evaluation and Management is a mini-ATLS course aimed at introducing medical students to trauma management, and the ASSET course and the Advanced Trauma Operative Management (ATOM) courses are aimed at increasing surgical competence and confidence in the operative management of penetrating injuries.[43] With decreasing national incidence of penetrating injuries, recent surgical residency graduates reported having performed one half the number of trauma operations compared to graduating surgical residents from 20 years ago, and on average, report having performed only 2.1 major vascular repairs—a concerning experience gap.[43-45] ASSET and ATOM courses include advanced cadaver, simulation, and team-based

training for various trauma explorations including the neck, chest, abdomen, and major vessels. Both ATOM and ASSET courses have reported significant improvement in self-reported confidence of participants in operatively managing penetrating trauma patients.[43,46,47] Resuscitative endovascular occlusion of the aorta (REBOA) is another technique newly being taught for trauma trainees and surgeons. ACS COT's Basic Endovascular Skills for Trauma (BEST) course and some ASSET courses have integrated this new technique for temporizing life-threatening bleeding within their curricula and provide simulation workshops. As with any new techniques, the evidence and best practices for REBOA are continually evolving.[48]

In addition to skills-based education, organizational improvement is another educational mission of our trauma system. For example, the Disaster Management and Emergency Preparedness course targets all healthcare providers, administrators, and public health personnel who may respond to major disasters, and teaches organizational principles for responding to disasters ranging from blast injuries to chemical attacks.[49] The Rural Trauma Team Development course is another organizational improvement course offered by the ACS COT that assists rural healthcare professionals and administrators in developing communication strategies to allow rapid transfer of trauma patients to more capable facilities.

Research

Scholarly trauma organizations form an integral part of trauma systems by advancing, synthesizing, and disseminating trauma research. The American Association for the Surgery of Trauma (AAST), founded in 1937, is the premier scholarly organization in the field of trauma and critically ill surgical patients. With approximately 1200 members from 30 countries, its annual meeting is attended by trauma healthcare providers across the world and provides a medium for the international community to exchange ideas and collaborate on scholarly ventures. The AAST publishes the *Journal of Trauma and Acute Care Surgery* (the leading source of peer-reviewed trauma publications), provides research funding and grants, facilitates multi-institutional studies, and provides mentorship opportunities for academic grant writing.[50] Several other countries and regions have scholarly trauma organizations that convene in regular meetings, such as the World Trauma Congress, the International Association for Trauma Surgery and Intensive Care, and the European Congress of Trauma and Emergency Surgery.

Other organizations focused on specific injury patterns are additional valuable academic assets within trauma systems. Organizations such as the Chest Wall Injury Society, American Spinal Injury Association, and the Brain Trauma Foundation provide the funding and medium for like-minded researchers to make discoveries that advance care for trauma patients. For example, the Chest Wall Injury Society publishes "Ribnars" that provide up-to-date evidence in managing patients with rib fractures, has completed multi-institutional studies to better inform best practices, and publishes consensus guidelines on rib fracture management for trauma centers to adopt.[51-54]

The Holy Grail: Zero preventable deaths after injury

The 2016 National Academies of Sciences, Engineering, and Medicine (NASEM) report, "A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury" estimated a 20% excess in mortality due to differential care among trauma centers.[55] This report underscored the need for a comprehensive national trauma system that builds on the military's knowledge of trauma patients gained during the Iraq and Afghanistan War. The report made 11 major recommendations that outlined the committee's finding for the need of national federal leadership for both the implementation and execution of a national trauma care system.[55] The report called for the White House to lead a national trauma system, designate authority to the Secretaries of the Department of Defense and the

Department of Health and Human Services, and coordinate military and civilian trauma system leadership in pursuit of *Zero Preventative Deaths*.[55] Civilian leaders were identified as ACS COT, American College of Emergency Physicians, National Association of EMS Physicians, National Association of Emergency Medical Technicians, and the Trauma Center Association of America.[55] In response to the report, the ACS COT highlighted ongoing leadership in regard to each of the recommendations listed, from research and quality improvement (eg, NTDB, TQIP), to education (eg, ATLS, ASSET, ATOM), and military engagement with the civilian trauma system through the Military Health System Strategic Partnership.[56] The ACS also published "The Blue Book: Military-Civilian Partnership for Training, Sustainment, and Readiness," which provides a template for trauma centers or systems wishing to establish military and civilian relationships. In response to NASEM's call for federal leadership in pursuit of zero preventable deaths, the United States Congress passed the 2019 Pandemic and All-Hazards Preparedness Act (PAHPA) which included the Mission Zero Act, creating a grant to facilitate civilian trauma center and military partnerships in pursuit of trauma care quality improvement. Estimates suggest that such collaborations may result in more than 15,000 lives saved each year.[57]

Impact of trauma systems on outcomes

Injury prevention

Primary injury prevention remains a cornerstone component of the modern trauma system at all levels. In response to reports of growing motor vehicle accident mortality, the National Traffic and Motor Vehicle Safety Act of 1966 established comprehensive motor vehicle standards and safety goals. According to national data published by National Highway Traffic Safety Administration (NHTSA), the fatality rate per 100 million motor vehicle miles traveled was more than 5.0 at that time.[58] Seatbelt, airbag, and crash performance regulations over subsequent years have decreased the fatality rate to 1.27 per 100 million motor vehicle miles by 2008.[59] Today, the Centers for Disease Control and Prevention's (CDC) National Center for Injury Prevention and Control maintains the Web-based Injury Statistics Query and Reporting System (WISQARS), which provides fatal and nonfatal injury, violent death, and cost of injury data in the United States.[60] In a multipronged approach to reduce the burden of injury, the CDC has organized public awareness campaigns and funded research in the fields of traumatic brain injury, violence prevention, home and recreational safety, motor vehicle safety, and opioid overdose prevention. Funded studies have led to many impactful changes in several local communities. A study on the impact of low-cost repairs of abandoned buildings and vacant lots to prevent violence has led to nearly 10,000 abandoned buildings throughout the United States being refurbished. These improvements have shown a 39% decrease in gun assaults, 19% decrease in other assaults, and long-term reductions in gun violence around remediated abandoned buildings.[61] Another CDC-funded study to identify the suicide burden in rural Iowa revealed that 76% of violent deaths in the state were suicides.[62] The research has elevated rural suicide into public spotlight and a new federal bill that aims to provide stress management programs and public campaigns to curb rural suicides is in the works. The CDC's injury prevention mission has already met legislative success, as its effort to build a national concussion surveillance system has led to passage of the Traumatic Brain Injury Program Reauthorization Act of 2018. This bill now funds the foundational data infrastructure to support the national concussion research agenda. In conjunction with the CDC, ACS COT's subcommittee on Injury Prevention and Control is establishing itself as another centralized resource for injury prevention research and advocacy. The subcommittee has published a "Gun Safety and Your Health" brochure for the general public to prevent firearm injuries and has outlined a comprehensive approach to establish hospital-based violence intervention programs.[63]

Bystander intervention

The American Heart Association has exemplified the importance of bystander response education. Bystander CPR (cardiopulmonary resuscitation) has improved outcomes and increased the chance of survival for patients suffering from cardiac arrest.[64] The potential impact of bystander intervention is significant for trauma patients, given that the vast majority of deaths occur before patients reach the hospital. For trauma patients younger than 65 years, there are 9 prehospital deaths for every in-hospital mortality. One estimate suggests that in 2014 alone, 30,000 of 147,000 trauma deaths may have been avoided with timely hemorrhage control.[65]

Building on the military's success with tourniquets, local EMS and trauma centers continue to lead successful public educational campaigns on using tourniquets to stop bleeding. These initiatives have translated into increased on-field tourniquet usage and better outcomes upon arrival to trauma centers.[66,67] In the aftermath of the tragic Sandy Hook Elementary School shooting in 2012, the ACS brought together a group of trauma surgery, emergency medical care, government, and law enforcement experts to discuss how survival rates can be improved for injured patients with severe bleeding. Their recommendations culminated in the Hartford Consensus, which catapulted efforts to improve survival for mass violence victims by training potential bystanders. In 2015, the White House launched the STOP THE BLEED public awareness campaign.[68] STOP THE BLEED has now trained more than 1 million people around the world. The 1-hour training session of non-medical persons has been shown to improve lay public confidence and proficiency in controlling severe bleeding using tourniquets.[69]

Emergency medical services

EMS is vital for efficiently triaging and transporting injured patients. Delayed EMS transport time from injury to the hospital has been associated with increased mortality.[70] With roots in the military, the modern day EMS started to take shape in the 1950s when a group including hospitals, police/fire departments, and funeral homes started unregulated coordination of patient care and transport. Since the 1966 "National Highway Traffic Safety Act" that standardized EMS training and the 1970 inception of the "National Registry of Emergency Medical Technicians," prehospital training and care have continued to evolve. In addition to basic life support (BLS) techniques such as basic spine stabilization and bag-valve-mask ventilation, many emergency medical technicians are now trained to provide advanced life support (ALS). ALS-certified providers can perform advanced maneuvers ranging from rapid sequence induction and endotracheal intubation to intravenous/intraosseous access and advanced medication administration.

Whether a trauma system with highly skilled emergency medical technicians improves outcomes remains contentious. Since an early study reporting that severely injured patients transported by EMS had worse survival compared to those transported by non-EMS providers (ie, bystanders), several studies have debated the benefits of performing potentially time-consuming invasive prehospital interventions compared to an expeditious "scoop and run" approach.[71] Several single-institutional studies in the United States and abroad have found that advanced prehospital procedures and longer on-scene time either negatively influence or do not impact survival for penetrating trauma victims in urban settings.[72-75] A systematic review of 46 studies comparing BLS vs ALS-level prehospital care reaffirmed that BLS appears to be the favorable strategy for penetrating trauma victims.[76] However, the quality of evidence remains low; the literature is largely limited to retrospective single-center studies and the best prehospital transport strategy for subgroups of trauma patients such as rural patients and blunt trauma patients remain unclear.

Although modern day EMS is a decentralized system with considerable regional practice variability, the National Highway Traffic Safety Administration (NHTSA) continues to set EMS standards and lead research efforts. There are now 4 levels of national standard curricula for prehospital EMS providers; in successive order of advanced training requirements, they include

first responders, basic emergency medical technicians (EMTs), intermediate EMTs, and EMT-paramedics. NHTSA laid the groundwork to develop evidence-based guidelines for prehospital care and has supported the development of several guidelines for trauma patients, including guidelines for prehospital external hemorrhage control and for air medical transportation.[77,78] NHTSA is also leading an effort to standardize data collection by EMS agencies through the National EMS Information System (NEMSIS).[79] NEMSIS now collects data on more than 30 million EMS activations from more than 10,000 EMS agencies across the country every year. NEMSIS can be queried by individual researchers who want to investigate their own ways to assess and advance our EMS system, and also publish federal and state-level reports to inform the public.

Triage

Accurate triage is important to balance the delivery of cost-effective and appropriate level of care. Trauma patients should be transported to trauma centers capable of addressing their injuries without risking long-transport times, yet unnecessary activation of costly trauma teams should be minimized. ACS COT's *Triage Decision Scheme* was first developed in 1986 and continues to form the basis for field triaging trauma patients across most EMS systems. The importance of correct field triage is well documented. Patients with moderate to severe injuries had significant lower risk of death when triaged to level I trauma centers vs large nontrauma centers.[80] On the other hand, the cost of care at a trauma center is nearly twice the cost of care at a nontrauma center.[81] Overtriage—inappropriate triage to a higher-level trauma center when a patient does not require such resources—is not innocuous. Recent estimates suggested that a 30% overtriage rate is potentially costing trauma systems an excess of $136 million annually.[82] Overtriage can overcrowd trauma centers and adversely impact patient care; in fact, a review of mass casualties from terrorist bombings showed a direct correlation between overtriage rates and the mortality rates of critically injured patients.[83]

ACS COT considers an undertriage rate of <5% and an overtriage rate of <35% to be acceptable targets for trauma systems.[84] Appropriate triage per ACS COT guidelines has been projected to save $568 million per year.[85] Unfortunately, both over- and undertriage remain prevalent. A study of trauma patients in California revealed an average 35% undertriage rate, especially among patients with older age, increasing co-comorbidities, or fall as a mechanism of injury.[86,87] Undertriage was also associated with increased mortality.[86,87] Although EMS providers are expected to follow triage protocols, a prospective cohort study found that EMS provider judgment was the most common triage mechanism used.[88] This has been partly attributed to poor validity of the ACS COT triage decision scheme for pediatric and elderly patients.[88,89] Compliance with prehospital triage protocols vary widely across EMS systems around the world, ranging from 21% to 94%.[90] However, studies have shown that nearly all such protocols fail to accurately identify severely injured patients, risking undertriage.[90,91] System-wide efforts to optimize prehospital triage continue, ranging from refining trauma team activation models within trauma centers to reducing EMS helicopter overutilization.[92] Locally, some EMS providers are now proactively conducting epidemiologic studies to anticipate and adapt to evolving local trauma needs.[93]

Rural trauma

Rural patients face geographic and resource barriers to timely high-quality trauma care. Approximately 15.9% of the US population lives more than an hour away from a level I or II trauma center.[92] Rural trauma patients have increased likelihood of undertriage and decreased likelihood of transportation to a level I or II trauma center.[94] Inappropriate undertriage to a nondesignated trauma center has been associated with a 30% increase in mortality within the first 48 hours.[95] Prehospital care is especially important for rural communities, as transport times can exceed 2 hours and total prehospital times can exceed 4 hours.[96] Although all EMS systems must have a

physician in charge of overseeing the care provided by their prehospital providers, in rural areas with a shortage of physicians, EMS units may function without appropriate oversight. Amidst these resource barriers, rural patients are at higher risk of suffering injuries. They are more likely to be at higher risk for workplace injury (ie, involved in jobs that require operating machinery) and two-thirds of all fatal motor vehicle accidents in the United States occur in rural areas.[97] The rural paramedic paradox (rural areas farthest from appropriate hospitals have the greatest EMS needs yet have the most trouble maintaining EMS services) is an unfortunate reality.[96]

Regionalized trauma networks

The regionalized trauma network (RTN) was first defined by The Department of Health and Human Resources as "a pre-planned, comprehensive, and coordinated statewide and local injury response network that includes all facilities with the capability to care for the injured. It is the system's inclusiveness, or range of pre-planned trauma center and non-trauma center resource allocation, that offers the public a cost-effective plan for injury treatment."[98] In short, RTN is a single entity comprised of acute care hospitals within a region working to reduce the burden of traumatic disease. To avoid ineffective distribution of resources and ensure sufficient experience in managing trauma patients within a RTN, the ACS COT currently recommends level I trauma centers admit at least 1200 trauma patients or 240 severely injured patients per year.[99]

A RTN may be an inclusive or exclusive system. An inclusive system (wherein many hospitals partake in trauma patient care to the extent of their capabilities and available resources) is generally favored over exclusive trauma systems (wherein trauma patient care is limited to several highly specialized tertiary and quaternary centers). In Ohio, inclusive RTN establishment was associated with lower patient mortality and increased utilization of non-level I trauma centers.[100] The same Ohio RTN establishment was also associated with decreased mortality for specific subgroups of injured patients, such as those who required trauma laparotomies or suffered traumatic brain injuries.[101,102] Similar findings were replicated in other US regions, such as in a Pennsylvania study (where incorporating smaller level IV trauma centers led to decreased mortality rates and better coordination among regional hospitals) and a study evaluating 24 different state trauma systems (severely injured patients had greater survival within inclusive trauma systems).[15,103] RTN's impact may come to fruition rapidly; one study reported that reduced mortality was seen within 2 years of establishing a RTN.[104]

Foreseeing that RTNs may help close the gap in rural trauma care, ACS COT has recommended incorporating existing rural hospitals within trauma systems as level III or IV trauma centers. Trauma regionalization allows closer working relationships among regional hospitals and their urban counterparts. Closer working relationships may entail more formalized transfer protocols and increased availability of consultation; in Hawaii, providing resources for rural hospitals to grow into level III trauma centers decreased the need to transfer rural trauma patients to remote higher level centers without adversely affecting patient outcomes.[105] However, the risk for secondary over-triage (during patient transfer) that may occur with closer regional partnerships should be remembered. A retrospective cohort study in Ohio found that a significant number of patients transferred from level III to level I or II trauma centers were discharged without requiring more intensive care within 48 hours.[106] Minimizing trauma care redundancy requires a streamlined data and imaging sharing system and active consultation infrastructure within RTNs. In fact, increased telemedicine and real-time consultation adoption were specific needs outlined by NASEM's 2016 report. With RTNs, the broader choice of facilities a patient may be transported to from injury site necessitates improvements to existing triage systems—which are largely limited to assessing the degree of injury—to more comprehensive scoring systems (ie, Need For Trauma Intervention, which accounts for a patient's physical reserve).[107]

Trauma registries and quality improvement

ACS COT-verified trauma centers participate in the NTDB and TQIP.[108] NTDB is the largest US trauma database, with more than 7.5 million electronic records from 900 trauma centers.[109] NTDB aims to inform the "medical community, the public, and decision makers about a wide variety of issues that characterize the current state of care for injured persons in our country."[109] This database is the primary source for outcomes research on US trauma patients. By 2010, NTDB was the data source for 286 peer-reviewed publications and has helped advance various aspects of trauma research including clinical outcomes, public policy, quality improvement, disparity assessment, and injury prevention.[110] ACS COT also uses NTDB to publish annual reports that highlight broad issues and trends characterizing the current state of care for injured persons.

TQIP was established in 2008 to facilitate quality improvement for individual trauma centers.[111] TQIP now collects data from more than 800 US trauma centers every year and creates risk-adjusted benchmarks for various trauma patient outcomes. Individual trauma centers receive feedback on their performance against these national benchmarks, along with quality improvement training and education to address center-specific deficiencies. Institutions have used TQIP for several practical improvements ranging from accurately assessing trauma readmission rates and revamping hospital policies to curb venous thromboembolism rates.[112,113] A recent multicenter study including 93 centers participating in TQIP showed that both major complication rates and risk-adjusted mortality improved after implementing TQIP.[114] The state of Michigan has leveraged its existing relationship between its trauma centers and a private healthcare payer (Blue Cross Blue Shield) and built the Michigan Trauma Quality Improvement on top of TQIP. Under this initiative, the private healthcare payer has further incentivized quality improvement by instituting a pay-for-participation rather than pay-for-performance model for trauma centers.[115]

In addition to participating in the NTDB and TQIP, levels I, II, and III trauma centers must institute hospital-run performance improvement and patient safety committees (PIPS). PIPS committees include the trauma program manager, an EMS representative, and physician representatives from surgery, emergency medicine, and radiology. The multidisciplinary team meets regularly to track performance, conduct peer case reviews, monitor compliance, and correct any hospital-specific problems of deficiencies. PIPS committees have reported various quality improvement successes, such as significantly decreasing ionizing radiation exposure for pediatric patients or reducing mortality through a multifaceted trauma program overhaul.[116,117]

Long-term outcomes

The impact of injury lasts well beyond hospitalization. Injured patients often face long-term social dysfunction, post-traumatic stress disorder, and chronic pain.[118-120] Patients with low resilience, low educational levels, and low household incomes are especially at risk of poor long-term outcomes after injury.[121,122] Identifying long-term sequelae for specific injuries is important because early intervention opportunities for high-risk groups may exist. Both TQIP and NTDB capture comprehensive hospitalization characteristics, but not long-term outcomes. Long-term outcomes of trauma patients are difficult to monitor due to variable trauma system utilization and poor follow-up.[123] Injured patients do not always present to well-structured RTNs, patients injured outside their immediate communities are less likely to follow up at their admitting trauma center, and arranging follow-up with a local hospital may be difficult. Most importantly, a national effort to track long-term trauma outcomes is lacking; posthospitalization data collection is left to the discretion of individual trauma registries.[124]

Minimizing readmissions is an important long-term outcome goal. Up to 50% of trauma readmissions and postdischarge emergency departments visits are not captured when patients present to hospitals different from their index trauma admission hospitals.[125] Patients most

commonly represent with superficial infectious complications and complications related to firearm injuries.[126] Although insurance status is less likely to affect trauma care provided during index hospitalization, insurance status significantly impacts trauma readmissions. Those who are poorly insured are less likely to follow up after trauma admissions, whereas Medicare patients are more likely to be healthcare super-utilizers after trauma discharge.[127,125] With an added layer of complexity, up to 19% of trauma patients may undergo a change in insurance status (gaining or losing coverage) after discharge, so discharge planning for trauma patients has an evolving barrier.[128] Nevertheless, studies have already identified many readmission risk factors including older age and frailty, discharge to skilled nursing or extended care facilities, history of falls, alcohol abuse, discharge against medical advice, firearm injuries requiring surgery, and interpersonal stressors.[126,129-131] Protective factors include access to home health services, early cognitive behavior therapy for acute stress disorder, and early multidisciplinary patient and family teaching.[132,133] Trauma centers must undertake early identification of readmission risk factors and discharge planning to mitigate readmissions. Widespread postdischarge data collection is needed to understand the true physiologic and psychologic burden of injury, better identify opportunities to improve long-term outcomes, and track the impact of intervention efforts. Of note, what constitutes a successful recovery after trauma requires further study. A recent study suggested that those who maintain or regain a cohesive sense of self and those highly engaged in their recovery process have positive assessments.[134]

Disaster preparedness

Disasters (both natural and unnatural) and mass casualties are inevitable in today's society. When disaster strikes, trauma systems are at the vanguard. Not even the largest and most resourceful trauma center can handle sudden patient surges on its own. The September 11 terrorist attacks and the Boston Marathon bombings remain vivid examples. Los Angeles County has published how their trauma system's disaster preparedness survived through tests of disasters.[135] As of 2009, Los Angeles county had 5 level I, 8 level II trauma centers, and other non-level I and II centers with predetermined agreements on how to respond to multicasualty disasters. When a multicasualty event occurs, an established central command alerts all these centers and receives live-time updates on the number of beds available at each center. Every center has made a priori agreements on the minimum number of patients it would take. This system has responded to several disasters in recent decades. During the LAX US Air and SkyWest Airline collision of 1991, all 30 injured patients who survived the crash were triaged efficiently throughout 13 trauma centers; all 30 patients survived. The system was used again during the 2006 Santa Monica farmer's market car crash (51 injured patients transported) and the 2008 Chatsworth Metrolink train crash (98 injured patients transported). A well-defined disaster plan allowed these patients to be triaged throughout many trauma centers and managed without overwhelming any individual trauma center.[135]

Despite the clear role for trauma systems to respond to disasters and the inevitability of disasters, the preparedness of most trauma systems within the United States are unclear. A simulation optimization study of disaster response in 25 major US cities was performed to see how existing trauma system resources would fare under various mass-casualty scenarios.[136] These simulations showed that cities with more concentrated trauma centers would have lower total and out-of-hospital mortality rates, and found that longer wait and transport times needed to transport patients to trauma centers predictably increased mortality and resource consumption.[136] Alarmingly, not all trauma systems had the capacity to provide adequate care. The need to lay out well-defined disaster plans, regularly practice their enhancement, and the readiness for postdisaster analysis all remain pressing needs of US trauma systems today.

The importance of disaster preparedness has been highlighted by the ongoing COVID-19 pandemic. The SARS-CoV-2 virus has pushed global healthcare systems to the limits of their resources—and in some cases, past breaking points. In recent weeks, efforts to reduce mortality have focused on "flattening the curve" wherein patients requiring hospitalization (in many cases

intensive care with ventilator support) do not supersede the healthcare systems' resources (the bar). With evolving projections portending national ventilator shortages, the ACS—within a few weeks of the pandemic outbreak—has issued strong guidance to ensure quality care for surgical and trauma patients amidst constrained resources. Building on the infrastructure and coordination already thriving in established trauma networks, the ACS has also provided a framework for establishing Regional Medical Operation Centers (RMOC) for the COVID-19 pandemic.[137] RMOC is defined as "a single point of shared situational awareness and information that can implement effective command and control for the medical response to a large-scale mass casualty incident or other scenario…[which] may involve a single county or scale up to an entire state or multi-state region."[137] Similar to how coordination between multiple trauma centers, EMS, and other entities that care for trauma patients have improved outcomes for injured patients, RMOCs may prove vital for our healthcare system to endure this challenge of an unprecedented scale in recent memory.

International trauma systems

Global overview

The burden of injury is global. According to the World Health Organization (WHO), more than 5 million deaths annually are attributed to traumatic injuries; more than 90% of these deaths occur in mid-to-low-income countries.[138] The WHO Trauma System Maturity Index classifies various national trauma systems into 4 categories based on the level of maturity and resources from level I (least mature) to level IV (most mature).[139] The index is evaluated on the domains of prehospital trauma care, facility based trauma care, education and training, and quality assurance. As expected, many high-income countries report mature trauma systems and lower trauma-related mortality compared to mid-to-low-income countries.[140] In an effort to reduce this disparity, the WHO has released a how-to guide for national quality improvement in trauma care through its "Guidelines for Trauma Quality Improvement Programmes."[139] Many mid-to-low-income countries have referred to these guidelines to conduct need assessments and inform policy development. However, only a minority of these countries have implemented these guidelines.[141] Even high-income countries have yet to establish truly comprehensive trauma systems. For example, many lack nationally implemented trauma registries.[140] Despite these shortcomings, the global burden of trauma as measured by disability adjusted life years (DALY)—a summative index that includes premature mortality and nonfatal outcomes measured as years lived with disability—is improving. Global DALY rates for injuries have decreased by 31%, and the rate of decline in DALY rates has been significant for all major injuries between 1990 and 2013.[142]

Prehospital systems

Middle-to-low-income countries often lack organized prehospital trauma systems at a national scale. Field-to-hospital transport is often undertaken in non-EMS specialized vehicles by individuals who lack certified training.[143-145] However, local efforts for organized prehospital care have improved outcomes in resource-constrained settings. For example, a gradual expansion of a skeleton prehospital system throughout Northern Iraq (including 135 paramedics and 7000 lay trauma responders who received 2-day courses in basic life support measures) led to a 13% reduction in trauma-related mortality over a 10-year period.[146] A rural Uganda community was able to build a new, highly utilized, and affordable EMS at an estimated cost of $0.93 per capita, and instituting formalized guidelines for trauma dispatch systems has led to decreased response time and optimal dispatch in Monterrey (Mexico) and Tehran (Iran), respectively.[147-149]

Many high-income countries have national EMS systems with certified first responders who can provide basic and advanced life support. Many, such as the United Kingdom in 2012, have

turned to the US trauma system as a model to replicate.[150] High-income countries do have system-wide variability in prehospital management strategies.[150] For instance, whereas the US prehospital model prioritizes rapid patient transport to trauma centers through a "scoop and run" approach, France's prehospital model more heavily emphasizes in-field triage and assessment by physicians.[151] Japan and Hong Kong's EMS systems are entirely run by paramedics, whereas many European countries have ambulances staffed by paramedics and specially trained physicians.[152-155] Similar to the United States, geography attributes to regional differences within national prehospital systems, with lower level of life support available in rural regions and less densely populated regions reliant on EMS support by helicopter.[140]

Trauma center care

The impact of an integrated trauma system on improved trauma patient outcomes is clear. One estimate suggests that if global survival rates for severe injuries mirror those in high-income countries, up to 2 million lives could be saved annually.[156] Optimally managing injured patients within the trauma facility is the pillar of every trauma system. Most mid-to-low-income countries lack formal hospital trauma care pathways and 24/7 availability of qualified surgeons to manage injured patients. Some countries such as Saudi Arabia and India do have well-equipped facilities and well-trained personnel, but this is limited to large urban hospitals.[157,158] Improving care pathways has shown early success within individual centers. A tertiary hospital in Thailand reported reduced mortality among thoracic trauma patients after establishing a dedicated rapid response team, while a tertiary hospital in China reduced mortality rates for severely injured patients through an interdisciplinary evaluation and resuscitation pathway, and a hospital in Colombia decreased mortality for traumatic injury patients through standardized trauma protocols.[159-161]

High-income countries have implemented coordinated trauma center care to varying degrees. Nearly 90% of hospitals in Norway that receive trauma patients had dedicated trauma teams, whereas only 20% of such hospitals in Finland had organized trauma teams.[162,163] Some high-income countries such as Ireland, Belgium, and France have yet to implement formalized management, transfer, and triage protocols among its trauma centers.[155,164,165] Others, such as the United States, Canada, and Hong Kong, have well-established trauma centers with dedicated protocols and dedicated trauma teams, built in accordance with the ACS-COT guidelines. Similar to US evidence, international data have shown that trauma systems improve outcomes of injured patients. A study of Canadian trauma systems across several provinces found that mortality was lower in provinces with high compliance to trauma system guidelines, particularly in patients with severe or acutely life-threatening injuries.[166] This association between adherence to formal trauma system guidelines and improved survival after injury has been replicated in other countries such as Hong Kong and Australia.[167,168]

Other components

Trauma registries rarely exist in mid-to-low-income countries due to the lack of digital resources to maintain a costly registry.[169] As of 2017, many countries with major trauma burden—including India, South Africa, Spain, China, and Brazil—have yet to develop nationwide trauma registries.[140] High-income countries have implemented national trauma registries to varying degrees. Several countries collaborate to form multinational registries, such as the Trauma Audit & Research Network (United Kingdom and Ireland), the National Trauma Registry Consortium (Australia and New Zealand), and the Scandinavian Trauma Registry (Scandinavian countries). Others, such as Spain and Greece, are still building their nationwide trauma registries, while Canada closed its national trauma registry in 2014. With respect to trauma education, a systematic review on the impact of trauma care systems in low and middle income countries reported

Table 1
Successful impact of trauma systems in the United States.

Domains	Organizations/programs	Successful impact
Injury prevention	National Highway Traffic Safety Administration Centers for Disease Control National Center for Injury Prevention and Control American College of Surgeons Committee on Trauma	National Traffic and Motor Vehicle Safety Act: decreased motor vehicle accident mortality Injury database: WISQARS Injury prevention research funding Public awareness campaigns Legislative advocacy
Bystander intervention	American College of Surgeons Committee on Trauma Federal government	Hartford Consensus STOP THE BLEED campaign: >1 million trained on tourniquet use
Emergency medical services (EMS)	National Highway Traffic Safety Administration Local EMS systems	Establishes EMS organizational and training standards NEMSIS database & EMS research expeditious field-to-hospital transport
Triage	American College of Surgeons Committee on Trauma Local EMS systems	Triage decision scheme publication Strategies to minimize over and under-triage
Regionalized trauma networks	Local regionalized trauma networks	Co-ordinated care between high-level and other regional trauma centers Decreased mortality and other adverse outcomes
Trauma registries and quality improvement	American College of Surgeons Committee on Trauma: National Trauma Data Bank Trauma Quality Improvement Program Performance Improvement and Patient Safety committee	Trauma research foundation National updates on state of trauma care Benchmarks for individual trauma centers to reduce mortality and morbidity

NEMSIS, National Emergency Medical Services Information System; WISQARS, Web-based Injury Statistics Query and Reporting System.

Table 2
Unmet opportunities for trauma systems in the United States.

Domains	Unmet Opportunities
Injury prevention	Federal funding for gun violence research
Emergency medical services (EMS)	Evidence for “scoop and run” vs invasive prehospital interventions Support for rural EMS
Triage	Adherence to triage decision scheme rather than individual judgment More comprehensive triage decision scheme that captures patients’ functional reserves Triage protocols to minimize over- and under-triage
Regionalized trauma networks	Further adoption of telemedicine and real-time consultation with trauma networks
Long-term outcomes	Database to track long-term outcomes Long-term outcomes research for specific injuries
Disaster preparedness	Well-defined disaster response protocols within trauma networks

that 18 of 32 assessed countries have published on the beneficial impact of trauma training programs.[170] ATLS courses are offered in many high income countries, but variations exist (ie, Japan Advanced Trauma Evaluation and Care course—Japan, European Trauma Course—Belgium).

Conclusion

The modern US trauma system has evolved over the course of a century. From surgeons near battlefields who decided who could and could not return to the heat of war, an intricate trauma system that spans the entire continuum of clinical care, research, education, advocacy, and disaster preparedness has emerged. Trauma systems across the globe have proven their ability to

improve patient outcomes. Despite the successful impact (Table 1), unmet needs and opportunities exist for trauma systems in the United States (Table 2).

The work has yet to be completed. Despite recognition of the burden of trauma and our system's critical role in improving patient outcomes, trauma remains severely underfunded; in 2016, trauma accounted for only 2.9% of the National Institutes of Health's extramural budget.[171] Accomplishing the mission Zero Preventable Deaths After Injury will require funding to match the scope of the continued injury epidemic and a ceaseless march to a truly comprehensive trauma system.

Acknowledgments

The Neil and Claudia Doerhoff Fund supports scholarly activities of Dr Choi. We would like to thank Dr Beatrice Sun for assistance with initial literature searches.

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