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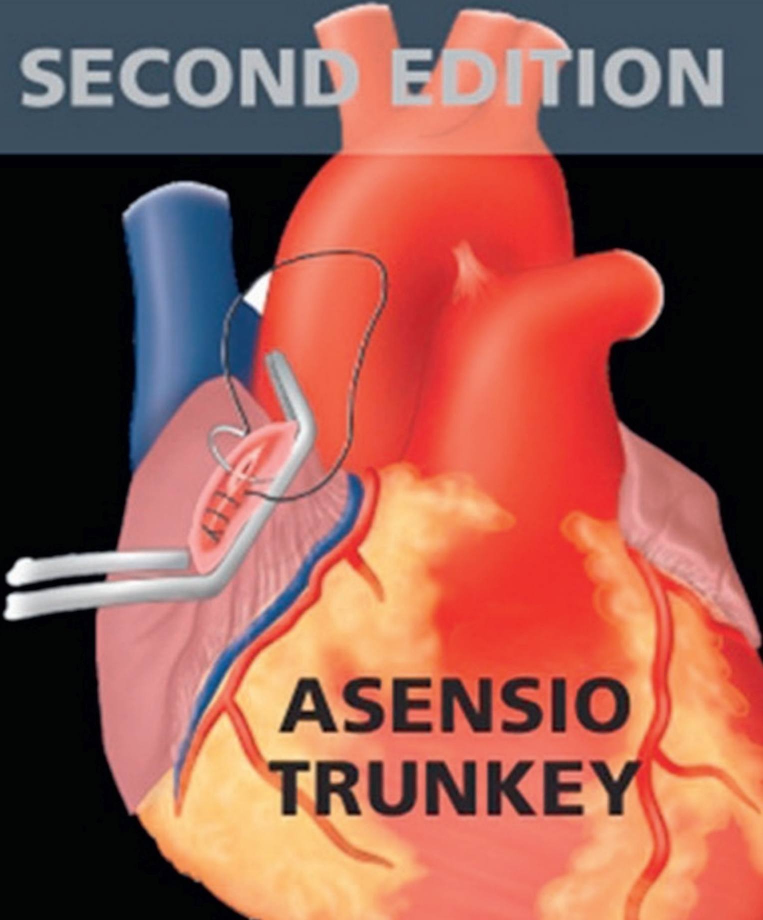

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CURRENT THERAPY OF TRAUMA AND SURGICAL CRITICAL CARE

2nd EDITION

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FOREWORD

Traumatic injury is the leading cause of death and disability for young adults and affects the lives of people all over the world. Comprehensive trauma surgical management must address prevention, the immediate needs of one victim or the sudden arrival of mass casualties, as well as rehabilitation and end-of-life care. The second edition of Current Therapy of Trauma and Surgical Critical Care is an invaluable resource for all who participate in the care of trauma patients, including military personnel and medical consultants.

Noted experts who are practicing academic trauma surgeons author the chapters and address controversies in an objective manner. Evidence-based guidelines are presented and discussed as are best practice recommendations based on years of busy clinical and operative experience. The critical care section of the book is well written and masterfully bridges basic physiology to the bedside evaluation of the patient.

New chapters in this edition address areas of growing importance including triage in civilian as well as military facilities, vascular injuries, difficult and complex injuries, recent lessons learned from the care of combat casualties, brain death, and organ donation.

The editors, Drs. Juan A. Asensio and Donald D. Trunkey, are visionary leaders who have spent their careers changing the way we view trauma care. They have revised and expanded this edition of *Current Therapy of Trauma and Surgical Critical Care* to help trauma systems meet new challenges in an increasingly global society.

Robert Dunlay, MD
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"If you get him to the operating room with a blood pressure, I will come in"

Growing up and training on the South Side of Chicago, I distinctly remember these words being spoken to me by my mentor during my cardiothoracic surgery residency. . . . I called him twice in 2 years. Trauma care has come a long way since that time and though many of the principles of management are the same and our focus always remains on the injury at hand, I now know that there is an ever evolving, complex, and sophisticated "trauma system" in place coordinating the efforts of many professionals and necessary to have that patient arrive on my operating table with a "blood pressure."

As *Current Therapy of Trauma and Surgical Critical Care* now enters its second edition, it is already one of the leading references for anyone involved in trauma. This current edition continues in the tradition of the *Current Therapy* series by updating, revising and expanding sections. There are new and updated sections on vascular injuries, developments in imaging technology, and up-to-date information on the newer ventilatory techniques. Edited by Dr. Juan Asensio and Dr. Donald Trunkey, two of the most well recognized names in trauma, it represents a comprehensive and authoritative text that covers the complete continuum of care with an emphasis on operative techniques for even the most complex of injuries.

The list of contributors represents a virtual "who's who" in trauma and critical care and is formatted to give the practicing professional practical, concise, and updated information focusing on organ systems and operative techniques. It is a compendium of what is considered common and accepted practice that is evidence based and clinically relevant, expert opinion, and discussion of controversial areas and challenges. There is something for everyone involved in trauma care, beginning with the history of trauma, the development of trauma systems, and the latest information regarding specific organ injury management, prevention, ICU care, mass casualty events, palliative care, rehabilitation, and outcomes.

Current Therapy of Trauma and Surgical Critical Care clearly represents a labor of love for Dr. Trunkey and now Dr. Asensio with a vision to create a comprehensive yet practical and concise reference for the trauma community. I would recommend it as worthwhile reading and a valuable reference for anyone involved in the care of the trauma patient

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PREFACE

It is now the dawn of the twenty-first century, and what a turbulent century it threatens to be. Once again it is a privilege and an honor to serve as the editor of *Current Therapy of Trauma and Surgical Critical Care*. This is actually the sixth edition; however, the editors have renumbered it as the second edition because we have added surgical critical care to this noble textbook.

One thing is constant: our world is turbulent and dangerous and will continue to be so for many future generations. A quick scan of the media, whether it is television, digital news, or the printed word, reveals that our world is currently experiencing multiple armed conflicts, with a large number of casualties from these conflicts. Our profession, perhaps the most godly of all professions, continues to be under siege; economic and market forces continue to encroach on the ability of doctors, and of course surgeons, to deliver the most optimum of care, especially, as it is often said, "To the least of these. . .," which means to the poorest of our brethren.

Amidst all of this turmoil, trauma surgeons and surgical critical care specialists have risen to the occasion by also taking on the burden of the management of acute care surgery. Once again trauma surgeons stand as pillars of strength, the quintessential "band of brothers." I rise to quote Shakespeare in describing trauma surgeons:

> "That he which hath no stomach to this fight,
> Let him depart. His passport shall be made,
> And crowns for convoy put into his purse.
> We would not die in that man's company
> That fears his fellowship to die with us.
> From this day to the ending of the world,
> But we in it shall be remembered—
> We few, we happy few, we band of brothers;
> For he today that sheds his blood with me
> Shall be my brother." (Henry V, Act IV, Scene 3)

It is my strong belief that the honor and the privilege of attempting to save a life not only in an operating room but also by counseling patients is indeed a noble task in the effort to eliminate trauma as a disease. We continue to hold on to the dream that we as leaders will eventually see a world in which there will be no wars and there will be greater understanding and more time and effort dedicated to the improvement of the human condition. We continue to believe that with our dedication we will make a difference, hoping to create bridges between people, leading to greater understanding and cooperation in human relations and in the field of scientific research. These ideals and goals remain lofty, but in speaking to my colleagues, this belief is strong and continues to motivate us all. I strongly believe that the alleviation of pain and suffering and the saving of lives remains a most important commitment for those who belong to this elite fraternity, the "band of brothers."

Once again I challenge, I urge, I beseech all of my colleagues in trauma surgery to go beyond the walls of academia to serve those who must be served, to use the power of our professions to exercise our consciences, to serve as leaders and advocates for human rights, to heal the wounded, and to teach the future generations of those who will be given the great gift to perform trauma surgery. We must be prepared to take the challenge to create peace and to heal wounds because it is we and those who have come before us who have been there, holding the hands of the wounded and injured, filled with pain and crying, often inwardly, when a life is lost, and continuing to struggle to save other lives.

IF—

By Rudyard Kipling

If you can keep your head when all about you
  Are losing theirs and blaming it on you,
If you can trust yourself when all men doubt you,
  But make allowance for their doubting too;
If you can wait and not be tired by waiting,
  Or being lied about, don't deal in lies,
Or being hated, don't give way to hating,
  And yet don't look too good, nor talk too wise:

If you can dream—and not make dreams your master;
  If you can think—and not make thoughts your aim;
If you can meet with Triumph and Disaster
  And treat those two impostors just the same;
If you can bear to hear the truth you've spoken
  Twisted by knaves to make a trap for fools,
Or watch the things you gave your life to, broken,
  And stoop and build 'em up with worn-out tools:

If you can make one heap of all your winnings
  And risk it on one turn of pitch-and-toss,
And lose, and start again at your beginnings
  And never breathe a word about your loss;
If you can force your heart and nerve and sinew
  To serve your turn long after they are gone,
And so hold on when there is nothing in you
  Except the Will which says to them: 'Hold on!'

If you can talk with crowds and keep your virtue,
  Or walk with Kings—nor lose the common touch,
If neither foes nor loving friends can hurt you,
  If all men count with you, but none too much;
If you can fill the unforgiving minute
  With sixty seconds' worth of distance run,
Yours is the Earth and everything that's in it,
  And—which is more—you'll be a Man, my son!

From *A Choice of Kipling's Verse* (1943)

Juan A. Asensio, MD, FACS, FCCM, FRCS, KM

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Trauma Systems

Development of Trauma Systems

Donald D. Trunkey

Modern trauma care consists of three primary components: prehospital care, acute surgical care or hospital care, and rehabilitation. Ideally, a society, through state (department, province, regional, etc.) government, should provide a trauma system that ensures all three components. The purpose of this chapter is to show how trauma systems have evolved, to discuss whether or not they work, and to define current problems.

From an historical viewpoint, it is an accepted concept that trauma care and trauma systems are inextricably linked to war. What is not appreciated is that trauma systems are not recent concepts. They date back to centuries before the Common Era. It is not known for certain whether the wounds of prehistoric humans were due primarily to violence or to accident. The first solid evidence of war wounds came from a mass grave found in Egypt and date to approximately 2000 BC. The bodies of 60 soldiers were found in a sufficiently well-preserved state to show mace injuries, gaping wounds, and arrows still in the body. The Smith Papyrus records the clinical treatment of 48 cases of war wounds, and is primarily a textbook on how to treat wounds, most of which were penetrating. According to Majno, there were 147 recorded wounds in Homer's *Iliad*, with an overall mortality rate of 77.6%. Thirty-one soldiers sustained wounds to the head, all of which were fatal. The surgical care for a wounded Greek soldier was crude at best. However, the Greeks did recognize the need for a system of combat care. The wounded were given care in special barracks (*klisiai*) or in nearby ships. Wound care was primitive. Barbed arrowheads were removed by enlarging the wound with a knife or pushing the arrowhead through the wound. Drugs, usually derived from plants, were applied to wounds. Wounds were bound, but according to Homer, hemostasis was treated by an "*epaoide*," that is, someone sang a song or recited a charm over the wound.

The Romans perfected the delivery of combat care and set up a system of trauma centers throughout the Empire. These trauma centers were called *valetudinaria* and were built during the first and second centuries AD. The remains of 25 such centers have been found, but significantly, none were found in Rome or other large cities. Of some interest, there were 11 trauma centers in Roman Britannia, more than currently exist in this area. Some of the *valetudinaria* were designed to handle a combat casualty rate of up to 10%. There was a regular medical corps within the Roman legions, and at least 85 army physicians are recorded, mainly because they died and earned an epitaph.

From elsewhere in the world came other evidence that trauma systems were provided for the military. India may well have had a system of trauma care that rivaled that of the Romans. The *Artasastra*, a book written during the reign of Ashoka (269–232 BC) documented that the Indian army had an ambulance service, with well-equipped surgeons and women to prepare food and beverages. Indian medicine was specialized, and it was the *shalyarara* (surgeon) who would be called upon to treat wounds. *Shalyarara* literally means "arrow remover," as the bow and arrow was the traditional weapon for Indians.

Over the next millennium, military trauma care did not make any major advances until just before the Renaissance. Two French military surgeons, who lived 250 miles apart, brought trauma care into the Age of Enlightenment.

Ambrose Paré (1510–1590) served four French kings during the time of the French-Spanish civil and religious wars. His major contributions to treating penetrating trauma included his treatment of gunshot wounds, his use of ligature instead of cautery, and the use of nutrition during the postinjury period. Paré was also much interested in prosthetic devices, and designed a number of them for amputees.

It was Dominique Larrey, Napoleon's surgeon, who addressed trauma from a systematic and organizational standpoint. Larrey introduced the concept of the "flying ambulance," the sole purpose of which was to provide rapid removal of the wounded from the battlefield. Larrey also introduced the concept of putting the hospital as close to the front lines as feasible in order to permit wound surgery as soon as possible. His primary intent was to operate during the period of "wound shock," when there was an element of analgesia, but also to reduce infection in the postamputation period.

Larrey had an understanding of problems that were unique to military surgery. Some of his contributions can best be appreciated by his efforts before Napoleon's Russian campaign. Larrey did not know which country Napoleon was planning to attack, and there was even conjecture about an invasion of England. He left Paris on February 24, 1812, and was ordered to Mentz, Germany. Shortly thereafter, he went to Magdeburg and then on to Berlin, where he began preparations for the campaign, still not knowing precisely where the French army was headed. In his own words, "Previous to my departure from the capital, I organized six divisions of flying ambulances, each one consisting of eight surgeons. The surgeons-major exercised their divisions daily, according to my instructions, in the performance of operations, and the application of bandages. The greatest degree of emulation, and the strictest discipline, were prevalent among all the surgeons."

The 19th century may well be described as the century of enlightenment for surgical care in combat. This was partly because of better statistical reporting, but also because of major contributions to patient care, including the introduction of anesthesia. During the Crimean War (1853–1856), the English reported a mortality rate of 92.7% in cases of penetrating wounds of the abdomen, and the French had a rate of 91.7%. During the American War Between the States, there were 3031 deaths among the 3717 cases of abdominal penetrating wounds, a mortality rate of 81.5%.

The Crimean War was noteworthy in having been the conflict in which the French tested a number of local antiseptic agents. Ferrous chloride was found to be very effective against hospital-related gangrene, but the English avoided the use of antiseptics in wounds. It was also during the Crimean War that two further major contributions to combat medicine were introduced when Florence Nightingale emphasized sanitation and humane nursing care for combat casualties.

The use of antiseptics was continued into the American War Between the States. Bromine reduced the mortality rate from hospital gangrene to 2.6% in a reported series of 308 patients. This contrasted with a mortality rate of 43.3% among patients for whom bromine was not used. Strong nitric acid was also used as an antiseptic in hospital gangrene, with a mortality rate of 6.6%. Anesthetics were used by federal military surgeons in 80,000 patients. Tragically, mortality rate from gunshot wounds to the extremities remained high, paralleling that reported by Paré in the 16th century. The mortality rate from gunshot fractures of the humerus and upper arm was 30.7%; those of the forearm, 21.9%; of the femur, 31.7%; and of the leg, 14.4%. The overall mortality rate from amputation in 29,980 patients was 26.3%.

The Franco-Prussian War (1870–1874) was marked by terrible deaths and the reluctance of some surgeons to use the wound antiseptics advocated by Lister. The mortality rate for femur fractures was 65.8% in one series, and ranged from 54.2% to 91.7% in other series. Late in the conflict, surgeons finally accepted Lister's recommendations, and the mortality rate fell dramatically.

During the Boer War (1899–1902), the British advised celiotomy in all cases of penetrating abdominal wounds. However, early results were abysmal, and a subsequent British military order called for conservative or expectant treatment.

During the early months of World War I, abdominal injuries had an unacceptable 85% mortality rate. As the war progressed, patients were brought to clearing stations and underwent surgery near the front, with a subsequent decrease in mortality rate to 56%. When the Americans entered the conflict, their overall mortality rate from penetrating abdominal wounds was 45%. One of the major contributions to trauma care during World War I was blood transfusion.

Since World War II, many contributions to combat surgical care have led to reductions in mortality and morbidity. Comparative mortality rates for various conflicts are listed in Table 1. Surgical mortality rates are shown in Table 2. The introduction of antibiotics and improvements in anesthesia, surgical techniques, and rapid prehospital transport are just a few of the innovations that have led to better outcomes.

TABLE 1: Percentage of Wounded American Soldiers Who Died from Their Wounds

War	Years	Number of Wounded Soldiers	Percentage of Wounded Soldiers Who Died of Wounds
Mexican War	1846–1848	3,400	15
American War Between the States	1861–1865	318,200	14
Spanish-American War	1898	1,600	7
World War I (excluding gas casualties)	1918	153,000	8
World War II	1942–1945	599,724	4.5
Korean Conflict	1950–1953	77,788	2.5
Vietnam Conflict	1865–1972	96,811	3.6

TABLE 2: Surgical Mortality Rates for Head, Chest, and Abdominal Wounds in Soldiers from U.S. Army

	Head	Thorax	Abdomen
World War I			
Number of soldiers	189	104	1816
Mortality rate (%)	40	37	67
World War II			
Number of soldiers	2051	1364	2315
Mortality rate (%)	14	10	23
Korean Conflict			
Number of soldiers	673	158	384
Mortality rate (%)	10	8	9
Vietnam Conflict			
Number of soldiers	1171	1176	1209
Mortality rate (%)	10	7	9

MODERN TRAUMA SYSTEM DEVELOPMENT

Between the two world wars, some significant advances were made in civilian trauma care. Lorenz Böhler formed the first civilian trauma system in Austria in 1925. Although initially directed at work-related injuries, it eventually expanded to include all accidents. At the onset of World War II, the Birmingham Accident Hospital was founded. It continued to provide regional trauma care until recently. By 1975, Germany had established a nationwide trauma system, designed so that no patient was more than 15 to 20 minutes from one of these regional centers. Due to the work of Harald Tscherne and colleagues, this system has continued into the present, and mortality rate has decreased by over 50% (Fig. 1).

In North America, foundations for modern trauma systems were being undertaken. In 1912, at a meeting of the American Surgical Association in Montreal, a committee of five was appointed to prepare a statement on the management of fractures. This led to a standing committee. One year later, the American College of Surgeons was founded, and in May 1922, the Board of Regents of the American College of Surgeons started the first Committee on Fractures with Charles Scudder, MD, as chair. This eventually became the Committee on Trauma. Another function begun by the college in 1918 was the Hospital Standardization Program, which evolved into the Joint Commission on Accreditation of Hospitals. One function of this standardization program was an embryonic start of a trauma registry with acquisition of records of patients who were treated for fractures. In 1926, the Board of Industrial Medicine and Traumatic Surgery was formed. Thus, it was the standardization program by the American College of Surgeons, the Fracture Committee

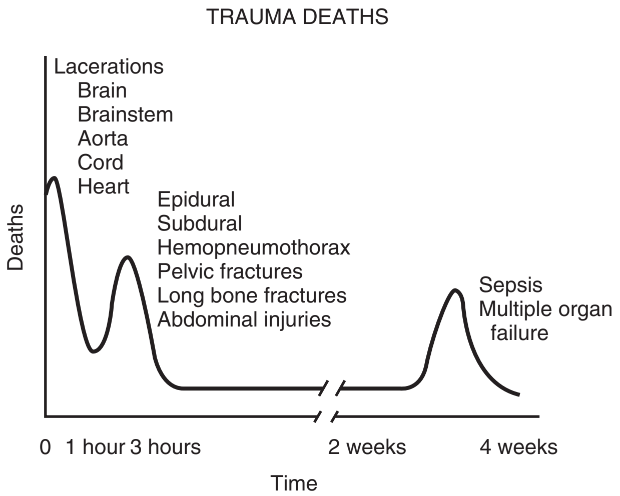

FIGURE 1 Trauma deaths have a trimodal distribution. The first death peak (approximately 50%) is within minutes of the injury. The second death peak (approximately 30%) occurs within a few hours to 48 hours. The third death peak (approximately 15%) occurs within 1 to 4 weeks and represents those patients who die from the complications of their injury or treatment. From a public health perspective, the first death peak can be addressed only by prevention, which is difficult, because part of this strategy means dealing with human behavior. The second death peak is best addressed by having a trauma system, and the third death peak requires critical care and research.

appointed by the American College of Surgeons, the availability of patient records from the Hospital Standardization Program, and the new Board of Industrial Medicine and Traumatic Surgery that provided the seeds of the trauma system.

In 1966, the first two trauma centers were established in the United States: William F. Blaisdell at San Francisco General Hospital and Robert Freeark at Cook County Hospital in Chicago. Three years later, a statewide trauma system was established in Maryland by R. A. Cowley. In 1976, the American College of Surgeons Committee on Trauma developed a formal outline of injury care called Optimal Criteria for Care of the Injured Patient. Subsequently, the task force of the American College of Surgeons Committee on Trauma met approximately every 4 years and updated their optimal criteria, which are now used extensively in establishing regional and state trauma systems and have recently been exported to Australia. Other contributions by the American College of Surgeons Committee on Trauma include introduction of the Advanced Trauma Life Support courses, establishment of a national trauma registry (National Trauma Data Bank), and a national verification program. The latter is analogous to the old hospital standardization program, and "verifies" by a peer review process whether a hospital's trauma center meets American College of Surgeons guidelines.

ARE TRAUMA SYSTEMS EFFECTIVE?

Since 1984, more than 15 articles have been published showing that trauma systems benefit society by increasing the chances of survival when patients are treated in specialized centers. In addition, two studies have shown that trauma systems also reduce trauma morbidity. In 1988, a report card was issued on the current status and future challenges of trauma systems. At that time, an inventory was taken of all state emergency medical service directors or health departments having responsibility over emergency and trauma planning. They were contacted via telephone survey in February 1987, and then were asked eight specific questions on their state trauma systems. Of the eight criteria, only two states, Maryland and Virginia, were identified as having all eight essential components of a regional trauma system. Nineteen states and Washington, D.C. either had incomplete statewide coverage or lacked essential components. Not limiting the number of trauma centers in the region was the most common deficient criterion.

In 1995, another report card was issued in the *Journal of the American Medical Association*. This report card was an update on the progress and development of trauma systems since the 1988 report. It was a more sophisticated approach, as it expanded the original eight criteria and was more comprehensive. According to the 1995 report, five states (Florida, Maryland, Nevada, New York, and Oregon) had all the components necessary for a statewide system. Virginia no longer limited the number of designated trauma centers. An additional 15 states and Washington, D.C. had most of the components of a trauma system.

The 1995 report card was upgraded at the Skamania Conference in 1998. There are now 35 states across the United States actively engaged in meeting trauma system criteria. In addition to the report card, the Skamania Conference evaluated the effectiveness of trauma systems. The medical literature was searched and all available evidence was divided into three categories: reports resulting from panel studies (autopsy studies), registry comparisons, and population-based research. Panel studies suffered from wide variation and poor inter-rater reliability, and the autopsies alone were deemed inadequate. This finding led to the general consensus that panel studies were only weak class III evidence. Despite these limitations, however, MacKenzie et al. concluded that when all panel studies are considered collectively, they do provide some face validity and support the hypothesis that treatment in a trauma center versus a nontrauma center is associated with fewer inappropriate deaths and possibly even disability. Registry evaluation was found to be useful for assessing overall effectiveness of trauma systems. Jurkovich and Mock concluded the data clearly did not meet class I evidence. Their critique of trauma registries included the following: there are often missing data, miscodings occur, there may be inter-rater reliability factors, the national norms are not population-based, there is little detail about the cause of death, and they do not take into account prehospital deaths. Despite these deficits, conference participants reached consensus, concluding that registry studies were better than panel studies but not as good as population studies. Finally, population-based studies were evaluated and found to comprise class II evidence. An advantage over registry studies is attributed to studying and evaluating a large population in all aspects of trauma care, including prehospital, hospital, and rehabilitation. Unfortunately, only a limited number of clinical variables can be evaluated, and it is difficult to adjust for severity of injury and physiologic dysfunction. Despite disadvantages with all three studies, the advantages may be applied to various individual communities to help influence public health policy with regard to trauma system initiation and evaluation.

Two recent studies document the effectiveness of trauma systems. The first is a comparison of mortality rates between Level I trauma centers and hospitals without a trauma center. The in-hospital mortality rate was significantly lower in trauma centers than in nontrauma centers (7.6% vs. 9.5%). This 25% difference in mortality rate was present 1 year after injury with a 10.4% mortality rate connected to trauma centers and 13.8% to nontrauma centers. The second study was an assessment of the State of Florida's trauma system, and this study confirmed a 25% lower mortality rate in designated trauma centers.

WHAT ARE THE CURRENT PROBLEMS?

In the global burden of disease study by Murray and Lopez, the world is divided into developed regions and developing regions. They also examine various statistics on a global level. The most useful statistic or means of measuring disability is the disability-adjusted life year

(DALY). This is the sum of life years lost due to premature death and years lived with disability adjusted for severity. By 2020, road traffic accidents will be the number 3 overall cause worldwide of DALYs. This does not include DALYs from war, which is number 8. In developed countries, road traffic accidents are the fifth highest cause of DALYs, and in developing regions, the second highest cause. One of the most difficult problems that we face in the coming years is how to provide reasonable trauma care and trauma system development in the developing regions of the world. Prehospital care is currently nonexistent in most of these developing countries. There are few, if any, trauma centers in the urban areas, and certainly none in the rural areas of the same countries. Even if there were such centers or a trauma system, rehabilitation is almost totally lacking, and therefore, the injured person would rarely be able to return to work or productivity after a severe injury.

As noted earlier, Europe has in the last century developed some statewide trauma systems. However, there is no concerted effort by the European Union (EU) to establish criteria for trauma systems or to coordinate trauma care among countries within the EU. Similarly, the EU does not have standards for prehospital care, nor is there a network of rehabilitation facilities that have standards and are peer reviewed. In theory, surgeons trained in one EU country should be able to cross the various national borders and to practice surgery, including trauma care, within these different EU countries. Again, there are no standards for what constitutes a trauma surgeon, and in fact, trauma surgery is a potpourri of different models. One model is exemplified by Austria, where trauma surgery is an independent specialty. Another model incorporates trauma surgical training into general surgery, and this includes France, Italy, The Netherlands, and Turkey. In a third model, the majority of trauma training is given with orthopedic surgery residency training. Belgium and Switzerland follow this model. The largest model provides trauma surgery training within specific specialties without any single specialty having any major responsibility for trauma training, and this model prevails in Denmark, Germany, Portugal, Estonia, Iceland, England, Norway, Finland, and Sweden.

Some of the most vexing problems in trauma surgery occur now in North America, particularly in the United States. This is in part due to changes in general surgery. It is predicted that there will be a *major* shortage of general surgeons in the United States within the next few years. General surgeons are now older, and more importantly, general surgeons are now subspecializing. We now have foregut, hepatobiliary, vascular, breast, and colorectal surgeons. The one thing they all have in common is they do not want to take trauma calls. Our medical specialty colleagues' night call is now in transition and hospitals are hiring so-called "hospitalists," who are trained in family medicine or internal medicine. In many instances, the hospital will pay their salaries to provide 24/7 calls, usually on a 12-hour shift basis. In some instances, possibly up to one third, various practice groups will pay these hospitalists to take their calls in hospital. Another trend affecting general surgery is the rapid transition to nondiscrimination regarding gender. At least 50% of entering medical students are now female, but only 7% (approximately 500 individuals) apply to surgery. The reasons given are long hours and poor lifestyle, as these women wish to combine professional careers with parenting responsibilities. There is an overall decrease in applications to general surgery, and the reasons for this are complex and multifaceted. One important reason is that general surgeons' incomes are approximately 50% less than those of some specialty surgeons. A more concerning reason, however, is lifestyle perceptions. Younger medical students and physicians tend to opt out of surgery, and they particularly abhor trauma surgery, because of the time commitment and related lifestyle issues. Another problem, which may be unique to the United States, is the decrease in operative cases in trauma. There has been a shift from penetrating trauma to blunt trauma and another shift to nonoperative management, particularly of liver and spleen injuries. General surgeons have compounded the problem by referring cases to surgeons who specialize in vascular surgery or chest surgery. Interventional radiologists also participate in management of certain traumatic injuries.

Another vexing problem in trauma care in the United States is the current demand for on-call pay by specialty surgeons. This is particularly true in orthopedics and neurosurgery. This on-call pay ranges from $1000 to $7000 a night. On average, a neurosurgeon in a Level I hospital would only be called in 33 times in the course of a year. In contrast, orthopedic surgeons average approximately 275 emergency cases during the year. Obviously, this responsibility could be shared between groups. Nevertheless, hospitals are being asked to pay on-call stipends to neurosurgeons that are quite large, considering the relatively low probability of being called in.

Other factors affecting trauma availability by specialty surgeons are freestanding ambulatory surgery centers where the surgeons can often avoid government regulations, do not have to take calls, and have hospitalists care for their patients at night.

These problems will be accentuated in the next few years as the elderly population (aged 65 and older) reaches 30% of the total population. Studies in the United States show that the mortality rate for people aged 65 and older in the intensive care unit is 3.5 times greater than that of younger people, and length of stay is longer. Unfortunately, the majority of these elderly patients who are seriously injured do not return to independent lifestyles following acute care.

SOLUTIONS

Correcting the problems in developing countries may be the most difficult. Most of these countries are totally lacking in the infrastructure for provision of a trauma system, including prehospital care, sufficient adequately trained surgeons, and rehabilitation services. International institutions such as the World Bank and World Health Organization would have to take a leading role in providing financial resources and training for prehospital care. This would be a potentially huge sum, because it would require creating and developing adequate communications, ambulances, and properly trained prehospital personnel. Similarly, provision of appropriately trained surgeons is equally problematic. Bringing surgeons to Western countries for training has been a problem because many of them do not return to their countries of origin. In my opinion, the optimal way to train these individuals would be for surgical educators from countries with mature trauma systems to spend time educating surgeons in the appropriate medical schools in their home countries. This is also problematic, because the quality of medical schools varies tremendously in developing nations. Furthermore, in addition to surgeons, anesthesiologists, critical care physicians, and nurses would have to be educated as well. The third component of a trauma system, rehabilitation, is almost totally lacking in developing countries. This element may not be as resource-dependent or costly as other components, but it would have to be developed concomitantly with prehospital and acute care.

The fundamental problem in developing regions is setting priorities. If we accept that DALYs are a reasonable approach to developing sound health care policy, then we can examine the 10 most common causes of DALYs. A rank order of the 10 most frequent DALYs in developing countries are: (1) unipolar major depression, (2) road traffic accidents, (3) ischemic heart disease, (4) chronic obstructive pulmonary disease, (5) cerebrovascular disease, (6) tuberculosis, (7) lower respiratory infections, (8) war, (9) diarrheal diseases, and (10) HIV (human immunodeficiency virus) infection. I am biased, but I believe that road traffic accidents may be the most cost-effective DALY to try to address. Prevention would clearly play a major role in chronic obstructive pulmonary disease, ischemic heart disease, and cerebrovascular disease, if the United States (among others) simply quit making and exporting cigarettes. I would also argue that as the world economy becomes more globalized and developing countries become economic powers in their own right, it is important for us to be involved early on in providing the infrastructure for managing health care in general and trauma care in particular.

The solutions in Europe are also somewhat problematic. I believe it is safe to say there are no standards being developed by the EU to address what constitutes optimal prehospital care. I think it is also safe to say that medical education, and specifically surgical training, varies markedly from country to country. The same could be said regarding critical care standards. The current approach to training a trauma surgeon in the EU is variable, and various specialists tend to provide this training. This approach is not necessarily negative, but there should be some standards that constitute the bare minimum in order for surgeons to come and go across borders and meet this standard of care. Within the EU, rehabilitation is also variable. One of the best examples of an excellent trauma rehabilitation program exists in Israel, which might represent a model for the EU. The best place to start would be for the EU to develop a document similar to the American College of Surgeons Optimal Criteria that would apply to all countries. It cannot be overemphasized that some type of review and verification must be applied to all three components of a trauma system—prehospital, acute care, and rehabilitation.

The solutions for the United States may be even more problematic than for developing countries. The reason is quite simple: the U.S. health care system is broken. A system that was historically “not for profit” has become “for profit.” Forty-four million individuals have no insurance, tens of millions are underinsured, and health care cost inflation is such that health care in the United States now accounts for a larger proportion of gross domestic product than in any other developed nation. Solving these issues obviously takes priority over solving the problems within trauma care, and yet they may be related.

There are many possible solutions to the health care problems in the United States from a global standpoint. Most economists argue that health care is a public good, similar to military, fire fighting, and police services. Through a public good model, there could be direct provision of care by government, or it could be contracted to insurance companies. Some have argued that this arrangement would cost more, that there would be loss of incentives, and that the system would continue to be double-tiered, because people could still buy additional insurance or pay extra for their health care. Another solution would be a public utility model, in which health care services would be regulated by local, state, or federal officials. The most positive aspect of this model is that there is public input. The disadvantage, particularly in the United States, is that given recent scandals associated with public utilities (e.g., Enron), there has been gaming of the system.

In anticipation of growth in the global economy, it would be possible to reduce pharmaceutical costs by outsourcing to developing countries. For years, the United States has imported nurses to make up for deficiencies in the training of nurses in the United States. A similar effort could be made by importing health care professionals, such as surgeons. In many ways, this model is completely unrealistic, because it removes professionals from countries, especially resource-poor countries, that need them the most.

The most reasonable model for the public would be to have universal health care with either a single payer or a multiple payer system. There would be a defined level of basic care, flexible co-payments, and catastrophic care, and freedom of choice to select professionals and hospitals would be maintained. Such a system would also emphasize disease prevention, patient education, and oversight of insurers. Malpractice would be arbitrated, and overdiagnosis and overtreatment would be curtailed. Although this last solution has merit, it is going to take time to bring about such changes.

The problems in trauma care in the United States are such that it is not possible to wait for a change in the overall health care system. Recently, a combined committee of the American College of Surgeons Committee on Trauma (ACS-COT) and the American Association for the Surgery of Trauma (AAST) has recommended a set of solutions for trauma systems. They have proposed that the American Board of Surgery (ABS) establish a primary board titled “The American Board of Emergency and Acute Care Surgery.” The curriculum would comprise 4 years of general surgery, followed by 2 years of trauma surgery, including some of the specialties within trauma. It would include critical care and vascular and noncardiac thoracic surgery. An opportunity would also include additional training in emergency orthopedics, neurosurgery, minor plastic surgery, and some interventional radiology as well. Essentially, the proposed curriculum would create a surgical hospitalist who would perform shift work and provide 24/7 coverage of nearly all surgical emergencies. One of the problems yet to be solved is how to provide continuity of care, particularly at shift change.

Prehospital care and rehabilitation are also problems that need to be solved. The committee has recommended that we develop optimal criteria standards for prehospital care that would include peer review and verification. Similarly, rehabilitation care needs development of optimal criteria standards with peer review and verification.

Trauma care and trauma systems in the Western Hemisphere are a microcosm of the rest of the world. Canada has provincial trauma systems and centers, but lacks a nationwide trauma system. Mexico, Central America, and South America have embryonic components of the trauma system, including trauma centers in many academic hospitals, but lack prehospital care, rehabilitation, and statewide trauma systems. This arrangement is particularly problematic for countries such as Colombia, where violence is a major contributor to trauma injuries. One could argue that as the economy becomes globalized, it will be important to have worldwide standards for trauma management and peer review. I consider this a challenge and an opportunity.

For the chapter’s Suggested Readings list, please visit the book at www.ExpertConsult.inkling.com.

Trauma Center Organization and Verification

Colonel (retired) Brian Eastridge and Erwin Thal

Please visit the book at www.ExpertConsult.inkling.com to read this chapter in full.

Suggested readings

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Trauma Center Organization and Verification

Colonel (retired) Brian Eastridge and Erwin Thal

The development of trauma care has been a synergistic relationship between the military and civilian medical environments for the past two centuries. During the Civil War, military physicians realized the utility of prompt attention to the wounded, early débridement and amputation to mitigate the effects of tissue injury and infection, and evacuation of the casualty from the battlefield. World War I saw further advances in the concept of evacuation and the development of echelons of medical care. With World War II, blood transfusion and resuscitative fluids were widely introduced into the combat environment, and surgical practice was improved to care for wounded soldiers. In fact, armed conflict has always promoted advances in trauma care due to the concentrated exposure of military hospitals to large numbers of injured people during a relatively short span of time. Furthermore, this wartime medical experience fostered a fundamental desire to improve outcomes by improving practice. In Vietnam, more highly trained medics at the point of wounding and prompt aeromedical evacuation decreased the battlefield mortality rate even further.

In 1966, the National Academy of Sciences (NAS) published "Accidental Death and Disability: The Neglected Disease of Modern Society" noting trauma to be one of the most significant public health problems faced by the nation. Concomitant with advances on the battlefield and the conclusions of the NAS was the formal development of civilian trauma centers. The developmental evolution has continued over the last four decades. Ten years later, in 1976, the American College of Surgeons produced the first iteration of injury care guidelines, the "Optimal Resources for the Care of the Injured Patient." This concept rapidly evolved into the development of integrated trauma systems with a formal consultation and verification mechanism to assess trauma standards of care at the organizational level. As a result, trauma centers and trauma systems in the United States have had a remarkable impact on improving outcomes of injured patients.

TRAUMA SYSTEM AND TRAUMA CENTER ORGANIZATION

Trauma System Organization

The organization of trauma systems and trauma centers is an effort to match the needs for injury care of a geographic population with the demand for trauma services. In this process, resources tend to be concentrated in areas of higher patient volume and acuity. At the core of the system organization is the Level I trauma center. Most of these Level I facilities are located at tertiary referral centers within major urban environments. Along with the patient characteristics, these centers foster the development of trauma system infrastructure elements including trauma leadership, professional resources, information management, performance improvement, research, education, outreach, and advocacy. By virtue of their inherently academic disposition, Level I centers generally serve as the regional resource for injury care. In addition, due to their size and resourcing, most are capable of managing large numbers of injured patients and have immediate availability of in-house trauma surgeons and ancillary trauma service teams.

The next tier of trauma center organization is the Level II trauma center. Like the Level I center, many of these facilities tend to be located in higher population density communities. The Level II centers aspire to similar standards as the Level I facilities with the exception that its accreditation is not contingent upon having a graduate medical education program, research capacity, education, or specific volume requirements. Approximately 84% of U.S residents have access to Level I or Level II trauma centers within 60 minutes of injury through the aeromedical evacuation system. The benefit of this concentration of resources manifest by Level I and II trauma centers has been demonstrated in the context of the association between trauma center volumes and trauma patient outcomes in which trauma center volume is directly associated with decreased average length of stay and improved patient mortality rates after injury. Recent epidemiologic studies of trauma patients show that the risk of death is significantly lower when care is provided in a trauma center rather than in a nontrauma center, which supports continued efforts at injury care regionalization. It has also been demonstrated that more severely injured patients with an injury severity score greater than 15 have lower mortality rates when treated at Level I trauma centers as compared to lower echelon centers.

The Level III trauma centers constitute the vast majority of trauma centers and are the last level of fully functional injury care. These hospitals serve smaller urban or suburban communities that do not have access to higher levels of trauma care. At Level III facilities, most injuries can be managed from resuscitation through operation and to rehabilitation. Level III facilities have the capacity to resuscitate, stabilize, and transport more severely injured patients to a higher level of definitive care.

Level IV trauma centers are generally located in rural environments with a paucity of resuscitative and surgical resources. The main capability for these hospitals is the recognition of injury and initial care phase. Owing to their lack of acute injury care resources, many of these facilities have standing interfacility transfer agreements within the trauma system.

Trauma Center Organization

The development and success of a trauma center is contingent upon two basic building blocks: hospital organizational support and medical staff support. First, the hospital and its leadership must have a firm administrative and financial commitment to the development of a trauma center, including incorporating the program into the formal organizational structure at a point commensurate with other clinical care departments of equal stead. The second foundation of trauma center development is medical staff support exhibited as thorough professional support, including specialty care services, encumbered by the care of the trauma patient. The basic organizational structure schematic is shown in Figure e1.

The core elements of a trauma center include the trauma team, the trauma service, and the trauma program, which has the ultimate responsibility for the entire trauma center. The trauma team consists of the provider and ancillary support personnel that respond to emergency department trauma activations.

Levels of response are guided by patient acuity and level of trauma center resources. Higher patient acuity with more robust resources, as in Level I and II trauma centers, encumbers a response from the general/trauma surgeon, emergency physician, anesthesia provider, resident trainees, trauma/emergency nursing, respiratory therapy, radiology technician, blood bank representative, security, and spiritual counsel. The team leader is the surgeon who is ultimately

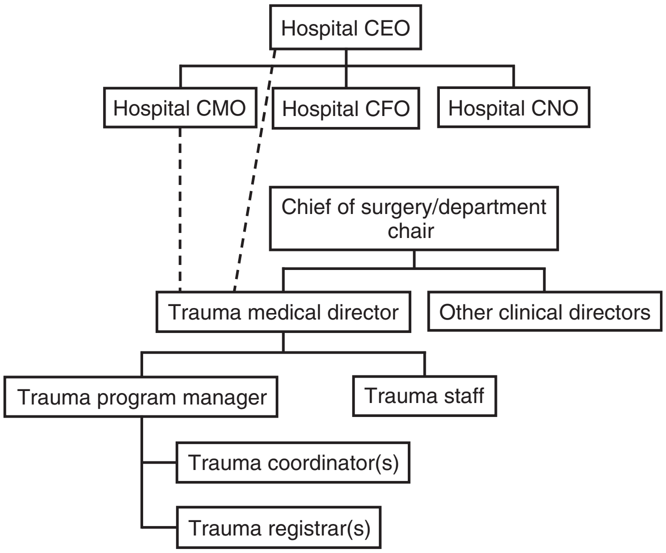

FIGURE E1 Trauma center organizational structure. CEO, Chief executive officer; CFO, chief financial officer; CMO, chief medical officer; CNO, chief nursing officer.

responsible for the patient's disposition and care, but more importantly, all members of the team work together to streamline patient care according to Advanced Trauma Life Support (ATLS) guidelines. The trauma service maintains the clinical responsibility for maintaining continuity of care in the multidisciplinary environment. In higher echelon trauma centers, the trauma service is often a formal clinical service or services under the guidance of trauma staff surgeons. In Level II facilities, these trauma patients are often admitted to the primary surgeon of record and the continuity and oversight to maintain service integrity are provided by the trauma medical director.

The trauma program within a trauma center is a multidisciplinary effort that supports injury care from resuscitation through rehabilitation. Integral staff elements within the trauma program are the trauma medical director, trauma staff, physician specialty staff (orthopedics, neurosurgery, emergency medicine, anesthesia, radiology), trauma program manager/trauma nurse coordinator(s), and trauma registrar(s). The key processes that distinguish a trauma center are performance improvement and multidisciplinary peer review.

Trauma Medical Director

The trauma medical director is a general surgeon, usually with a specified interest or specialty training in trauma, who functions as the key leader within the trauma medical staff. The trauma medical director should be knowledgeable in the field and proficient in the technical skills of the profession. More importantly, this individual should have authority over all aspects of the trauma program, including the development, alteration, and implementation of clinical practice guidelines, coordinating trauma and trauma specialty services, monitoring performance improvement and outcomes assessment, and providing strategic planning guidance for the program. Less tangible, though no less vital, requirements of this position include administrative and committee responsibility and team building responsibilities.

Trauma Program Manager/Trauma Nurse Coordinator

The position of trauma program manager and trauma nurse coordinator are dual positions or can be coalesced into a single position depending upon the size and volume of the trauma program. This position is

TABLE E1: Roles of the Trauma Program Manager/Trauma Nurse Coordinator

Role	Definition
Clinical	Coordinating continuity and quality of trauma care in multidisciplinary environment
Administrative	Helps manage the operational and fiscal activities of the program as well as participates in various committee activities
Leadership liaison	Team building Promotes trauma program at local regional, state and national levels
Educational	Trains trauma program staff Provides resource plan to train local facilities Promotes outreach programs
Registry	Oversight of trauma registry data collection and accuracy
Performance improvement	Key proponent of trauma program performance improvement process from discovery through loop closure
Research	Promotes accurate and reliable data collection and analysis for performance improvement and facilitates clinical research endeavors
System advocate	Trauma system development, funding, patient advocate, injury prevention, public education and outreach

filled by a highly specialized registered nurse with advanced trauma training who is integral to the development, coordination, implementation, and evaluation of trauma care within the program. This position serves as a key leadership liaison between the staff and process elements within the program (Table e1).

Trauma Registrar

Trauma registry personnel are required in trauma programs on the basis of allocation of one registrar per 500 to 1000 trauma admissions per year. The goal of maintaining such a record is to have a repository of trauma patient data, which can be used for trauma program performance improvement or can be evaluated alone or in conjunction with other trauma registry databases in order to answer public health questions or provide trauma outcomes analysis. Registry databases are collected in standardized products to facilitate analysis and transfer of information between institutions and to state and national repositories. Data are coded in standard formats and are de-identified prior to analysis to safeguard individual protected health information. The Trauma Quality Improvement Program developed by the American College of Surgeons Committee on Trauma utilizes composite registry data analysis to formulate clinical benchmarks for injury management. The value of the registry is further manifest in its ability to support evidence-based improvements in clinical practice, public safety and injury prevention initiatives, and legislation directed toward improved injury care.

TRAUMA PERFORMANCE IMPROVEMENT PROCESS

The trauma performance improvement process is perhaps the most important of all trauma program processes in order to assure the highest quality of care is rendered to each injured patient. The importance of this process is vital from a functional and verification perspective. In fact, the majority of verification visit time is spent evaluating patient records and performance improvement. Trauma performance improvement begins with the definition of injury based upon ICD-9 codes 800 through 959.9. This process is based upon the tenets of program monitoring, which should be current and based on reliable data. Outliers are identified and serve as indicators of deviation from the standard of care that require further review and discussion. A decision must be made as to whether no action is required or corrective action needs to be instituted in the form of individual counseling, education, policy review, peer review, or multidisciplinary trauma committee review. Once the corrective action has been implemented, the performance indicator returns to the monitoring phase. If performance measures are acceptable, the "loop" is closed (Fig. e2).

Performance improvement measures can be categorized as process measures or outcome measures. Some commonly assessed performance measures are listed here:

- Appropriate trauma activation
- Track overtriage/undertriage
- System delays
- Response times
- Trauma center diversion time and cause
  - Intensive care unit (ICU)
  - Operating room
  - Emergency department capacity
  - Other
- Delays to operating room
- Time to computed tomography for altered level of consciousness

From the outcome perspective, frequently evaluated outcome measures include hospital and ICU lengths of stay, morbidity rates, and mortality rates. In particular, all trauma deaths require review within the performance improvement process and each death is classified as to whether it was a death with no opportunity for improvement (nonpreventable), an anticipated death with opportunity for improvement (possibly preventable), or an unanticipated death with opportunity for improvement (preventable).

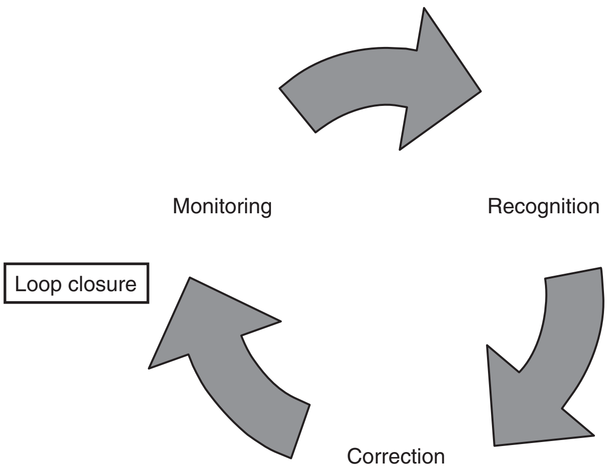

FIGURE E2 Performance improvement loop closure.

TRAUMA CENTER VERIFICATION

The American College of Surgeons developed and implemented the Consultation/Verification Program in 1987. This program validates the resources for trauma care at trauma centers. The implicit mission of the trauma center verification and consultation process is to develop and sustain injury management guidelines for the purpose of optimizing trauma care. "This objective can be accomplished through a voluntary review of potential and existing trauma centers so that trauma centers may provide an organized and systemic approach to the care of the injured patient. *Resources for Optimal Care of the Injured Patient: 2006* outlines the resources necessary for optimal care and is used as a guide for the development of trauma centers throughout the United States." The basic premise for trauma center verification is to ascertain whether a trauma center meets the guidelines outlined in the American College of Surgeons document. Trauma center designation is a process, which is geopolitical in origin and is the ultimate responsibility of the local, regional, or state health care agency with which the trauma center is affiliated. In some states, trauma center designation identifies the regional provision of trauma care to particular hospital facilities and is required to receive uncompensated care funding from governmental agencies. The designation and verification processes are complementary: designation recognizes capability whereas verification confirms adherence to established guidelines. Effective trauma centers require both processes to affirm institutional and governmental commitment to the success of the trauma program.

Consultation

The consultation process is conducted utilizing the same format as the formal verification process. The rationale to conduct a consultation review would be to assess trauma care or to prepare a center for a verification visit. The subsequent consultation report can address the specific tenets of injury management, which directed the consultation, or more globally address any deficiency, which would require remediation prior to a verification visit.

Verification

The verification visit is contingent upon approval by the responsible designating authority or in the absence of such an agency, upon request of an individual hospital. Once this occurs, the facility completes the verification application for a site visit followed by completion of the prereview questionnaire. A review team is selected, the composition of which may be dependent upon the requirements of the designating authority. The verification review consists of a prereview dinner meeting and an onsite review characterized by a tour of the facility followed by an in-depth chart review and performance improvement process analysis. Other aspects of the trauma program including prevention, prehospital care, trauma service organization, educational activities, and rehabilitation programs are also evaluated. The preparation for verification and the verification process itself have demonstrated significant impact on trauma patient care and lowering of injury mortality rates.

SUGGESTED READINGS

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Injury Severity Scoring: Its Definition and Practical Application

Turner M. Osler, Laurent G. Glance, and Edward J. Bedrick

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Trauma Scoring

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Injury Severity Scoring: Its Definition and Practical Application

Turner M. Osler, Laurent G. Glance, and Edward J. Bedrick

The urge to prognosticate following trauma is as old as the practice of medicine. This is not surprising, because injured patients and their families wish to know if death is likely, and physicians have long had a natural concern not only for their patients' welfare but for their own reputations. Today there is a growing interest in tailoring patient referral and physician compensation based on outcomes, outcomes that are often measured against patients' likelihood of survival. Despite this enduring interest, the actual measurement of human trauma began only 50 years ago when DeHaven's investigations into light plane crashes led him to attempt the objective measurement of human injury. Although we have progressed far beyond DeHaven's original efforts, injury measurement and outcome prediction are still in their infancy, and we are only beginning to explore how such prognostication might actually be employed.

In this chapter, we examine the problems inherent in injury measurement and outcome prediction, and then recount briefly the history of injury scoring, culminating in a description of the current de facto standards: the Injury Severity Score (ISS), the Revised Trauma Score (RTS), and their synergistic combination with age and injury mechanism into the Trauma and Injury Severity Score (TRISS). We will then examine the shortcomings of these methodologies and discuss newer scoring approaches that have been proposed as improvements. Finally, we will speculate on how good prediction can be and to what uses injury severity scoring should be put given these constraints. We will find that the techniques of injury scoring and outcome prediction have little place in the clinical arena and have been oversold as means to measure quality. They remain valuable as research tools, however.

INJURY DESCRIPTION AND SCORING: CONCEPTUAL BACKGROUND

Injury scoring is a process that reduces the myriad complexities of a clinical situation to a single number. In this process, information is necessarily lost. What is gained is a simplification that facilitates data manipulation and makes objective prediction possible. The expectation that prediction accuracy will necessarily be improved by scoring systems is unfounded; however, when intensive care unit (ICU) scoring systems have been compared to clinical acumen, the clinicians usually perform better.

Clinical trauma research is made difficult by the seemingly infinite number of possible anatomic injures, and this is the first problem we must confront. Injury description can be thought of as the process of subdividing the continuous landscape of human injury into individual, well-defined injuries. Fortunately for this process, the human body tends to fail structurally in consistent ways. Le Fort discovered that the human face usually fractures in only three patterns despite a wide variety of traumas, and this phenomenon is true for many other parts of the body. The common use of eponyms to describe apparently complex orthopedic injuries underscores the frequency with which bones fracture in predictable ways. Nevertheless, the total number of possible injuries is large. The Abbreviated Injury Scale is now in its fifth edition (AIS 2005) and includes descriptions of more than 2000 injuries (increased from 1395 in AIS 1998). The International Classification of Diseases, Ninth Revision (ICD-9) also devotes almost 2000 codes to traumatic injuries. Moreover, most specialists could expand by severalfold the number of possible injuries. However, a scoring system detailed enough to satisfy all specialists would be so demanding in practice that it would be impractical for nonspecialists. Injury dictionaries thus represent an unavoidable compromise between clinical detail and pragmatic application.

It is perhaps surprising that two entirely separate lexicons exist to describe individual traumatic injuries. Although both the AIS and ICD-9 have long histories; they arose in response to very different needs. The ICD was intended to create a finite number of categories that encompassed all possible morbid conditions (Benichou, 2000). The AIS, by contrast, was designed to include only injuries, and further, to assign a general measure of severity (1–6) for each injury. Because AIS was created specifically to describe traumatic injuries, it might seem a more natural lexicon to employ in trauma scoring. However, the ubiquity of ICD-9 coding has proved irresistible, and currently both AIS and ICD-9 lexicons are used in the description of human trauma. The existence of two competing systems for recording injuries complicates both injury scoring and the comparison of scoring results because the lexicons are so deeply incompatible that no unambiguous matching can be constructed to translate between AIS and ICD-9. Because ICD-9 codes are routinely collected, and thus have an effective collection cost of zero, it is possible that, despite its shortcomings, ICD-9 coding will displace the modestly more expensive AIS system over time.

Although an "injury" is usually thought of in anatomic terms, physiologic injuries at the cellular level, such as hypoxia or hemorrhagic shock, may also be important. Not only does physiologic impairment figure prominently in the injury description process used by emergency paramedical personnel for triage, but such descriptive categories are crucial if injury description is to be used for accurate prediction of outcome. Thus, the outcome after splenic laceration hinges more on the degree and duration of hypotension than on degree of structural damage to the spleen itself. Because physiologic injuries are by nature evanescent, changing with time and therapy, reliable capture of this type of data can be challenging.

The ability to describe injuries consistently on the basis of a single descriptive dictionary guarantees that similar injuries will be classified as the same. However, in order to compare different injuries, a scale of severity is required. Severity is usually interpreted as the likelihood of a fatal outcome; however, length of stay in an intensive care unit, length of hospital stay, extent of disability, or total expense that is likely to be incurred could each be considered measures of severity as well.

In the past, severity measures for individual injuries have generally been assigned by experts. Ideally, however, these values should be objectively derived from injury-specific data. Importantly, the severity of an injury may vary with the outcome that is being contemplated. Thus, a gunshot wound to the aorta may have a high severity when mortality is the outcome measure, but a low severity when disability is the outcome measure. (That is, if the patient survives, he or she is likely to recover quickly and completely.) A gunshot wound to the femur might be just the reverse in that it infrequently results in death but often causes prolonged disability.

Although it is a necessary first step to rate the severity of individual injuries, comparisons between patients or groups of patients is of greater interest. Because patients typically have more than a single injury, the severity of several individual injuries must somehow be combined to produce a single overall measure of injury severity. Although several mathematical approaches of combining separate injuries into a single score have been proposed, it is uncertain which of these formulas is most correct. The severity of the single worst injury, the product of the severities of all the injuries a patient has sustained, and the sum of the squared values of severities of a few of the injuries a patient has sustained have all been proposed, and other schemes are likely to emerge. The problem is made still more complex by the possibility of interactions between injuries. We will return to this fundamental but unresolved issue later.

As noted, anatomic injury is not the sole determinant of survival. Physiologic derangement and patient reserve also play crucial roles. A conceptual expression to describe the role of anatomic injury, physiologic injury, and physiologic reserve in determining outcome might be stated as follows:

$$\text{Outcome} = \text{Anatomic Injury} + \text{Physiologic Injury} + \text{Patient Reserve} + \text{Error}$$

Our task is thus twofold: First, we must define summary measures of anatomic injury, physiologic injury, and patient reserve. Second, we must devise a mathematical expression combining these predictors into a single prediction of outcome, which for consistency will always be an estimated probability of survival. We will consider both of these tasks in turn. However, before we can consider various approaches to outcome prediction, we must briefly discuss the statistical tools that are used to measure how well predictive models succeed in the tasks of measuring injury severity and in separating survivors from nonsurvivors.

TESTING A TEST: STATISTICAL MEASURES OF PREDICTIVE ACCURACY AND POWER

Most clinicians are comfortable with the concepts of sensitivity and specificity when considering how well a laboratory test predicts the presence or absence of a disease. Sensitivity and specificity are inadequate for the thorough evaluation of tests, however, because they depend on an arbitrary cut-point to define "positive" and "negative" results. A better overall measure of the discriminatory power of a test is the area under the receiver operation characteristic (ROC) curve, often abbreviated as AUC (area under the curve). Formally defined as the area beneath a graph of sensitivity (true positive proportion) graphed against 1 – specificity (false positive proportion), the AUC can perhaps more easily be understood as the proportion of correct discriminations a test makes when confronted with all possible comparisons between diseased and nondiseased individuals in the data set. In other words, imagine that a survivor and a nonsurvivor are randomly selected by a blindfolded researcher, and the scoring system of interest is used to try to pick the survivor. If we repeat this trial many times (e.g., 10,000 or 100,000 times), the area under the ROC curve will be the proportion of correct predictions. Thus, a perfect test that always distinguishes a survivor from a nonsurvivor correctly has an AUC of 1, whereas a useless test that picks the survivor no more often than would be expected by chance alone has an AUC of 0.5.

A second salutary property of a predictive model is that it has clarity of classification. That is, if a rule classifies a patient with an estimated chance of survival of 0.5 or greater to be a survivor, then ideally the model should assign survival probabilities near 0.5 to as few patients as possible and values close to 1 (death) or 0 (survival) to as many patients as possible. A rule with good discriminatory power will typically have clarity of classification for a range of cut-off values.

A final property of a good scoring system is that it is well calibrated; that is, it performs consistently throughout its entire range, with 50% of patients with a 0.5 predicted mortality actually dying, and 10% of patients with a 0.1 predicted mortality actually dying. Although this is a convenient property for a scoring system to have, it is not a measure of the actual predictive power of the underlying model and predictor variables. In particular, a well-calibrated model does not have to produce more accurate predictions of outcome than a poorly calibrated model. Calibration is best thought of as a measure of how well a model fits the data, rather than how well a model actually predicts outcome. As an example of the malleability of calibration, Figure e1A to C displays the calibration of a single ICD-9 Injury Severity Score (ICISS) (discussed later), first as the raw score and then as a simple mathematical transformation of the raw score. Although the addition of a constant and a fraction of the score squared add no information and do not change the discriminatory power based on AUC, the transformed score presented in Figure e1B is dramatically better calibrated. Calibration is commonly evaluated using the Hosmer Lemeshow (HL) statistic. This statistic is calculated by first dividing the data set into 10 equal deciles (by count or value) and then comparing the predicted number of survivors in each decile to the actual number of survivors. The result is evaluated as a chi-square test. A low value for the HL statistic (corresponding to a high p value) implies that the model is well calibrated. Unfortunately, the HL statistic is sensitive to the size of the data set, with very large data sets uniformly being declared "poorly calibrated." Conversely, if the number of possible predictive categories is small (<6) the HL statistic will almost always find that a model is "well calibrated." Finally, the creators of the HL statistic have noted that its actual value may depend on the arbitrary groupings used in its calculation, and this further diminishes the HL statistic's appeal as a general measure of calibration.

In sum, the ROC curve area is a measure of how well a model distinguishes survivors from nonsurvivors, whereas the HL statistic is a measure of how carefully a model has been mathematically fitted to the data. In the past, the importance of the HL statistic has been overstated and even used to commend one scoring over another. This represents a fundamental misapplication of the HL statistic. Overall, we believe less emphasis should be placed on the HL statistic.

The success of a model in predicting death is thus measured in terms of its ability to discriminate survivors from nonsurvivors (the AUC statistic) and its calibration (HL statistic). In practice, however, we often wish to compare two or more models rather than simply examine the performance of a single model. The procedure for model selection is a sophisticated statistical enterprise that has not yet been widely applied to trauma outcome models. One promising avenue is an information theoretic approach in which competing models are evaluated based on their estimated distance from the true (but unknown) model in terms of information loss. Although it might seem impossible to compare distances to an unknown correct model, such comparisons can be accomplished by using the Akaike information criterion and related refinements.

Two practical aspects of outcome model building and testing are particularly important. First, a model based on a data set usually performs better when it is used to predict outcomes for that data set than for other data sets. This is not surprising, because any unusual features of that data set will have been incorporated, at least partially, into the model under consideration. The second, more subtle, point is that the performance of any model depends on the data evaluated. A data set consisting entirely of straightforward cases (i.e., all patients are either trivially injured and certain to survive or overwhelmingly injured and certain to die) will make any scoring system seem accurate. But a data set in which every patient is gravely but not necessarily fatally injured is likely to cause the scoring system to perform no better than chance. Thus, when scoring systems are being tested, it is important first that they be developed in unrelated data sets and second that they be tested against data sets typical of those expected when the scoring system is actually used. This latter requirement makes it extremely unlikely that a universal equation can be developed, because factors not controlled for by the prediction model are likely to vary among trauma centers.

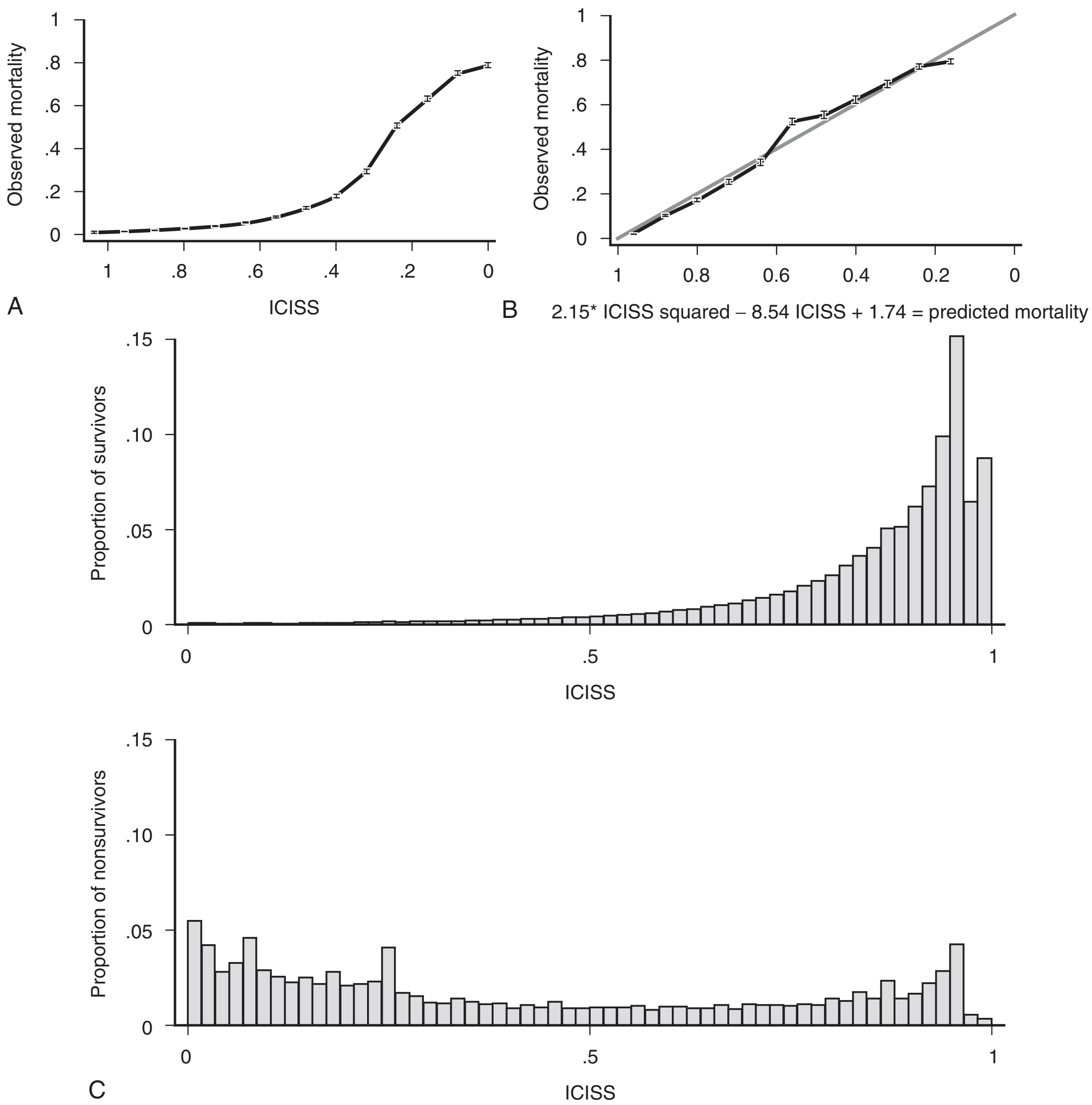

FIGURE E1 **A,** Survival as a function of ICD-9 Injury Scoring System (ICISS) score (691,973 patients from the National Trauma Data Bank [NTDB]). **B,** Survival as a function of ICISS score mathematically transformed by the addition of an $ICISS^2$ term (a "calibration curve"). Note that although this transformation does not add information to (or change the discrimination [receiver operation characteristic value] of) the model, it does substantially improve the calibration of the model (691,973 patients from the NTDB). **C,** ICISS scores presented as paired histograms of survivors *(above)* and nonsurvivors *(below)* (691,973 patients from the NTDB).

MEASURING ANATOMIC INJURY

Measurement of anatomic injury requires first a dictionary of injuries, second a severity for each injury, and finally a rule for combining multiple injuries into a single severity score. The first two requirements were addressed in 1971 with the publication of the first AIS manual. Although this initial effort included only 73 general injuries and did not address penetrating trauma, it did assign a severity to each injury ranging from 1 (minor) to 6 (fatal). No attempt was made to create a comprehensive list of injuries, and no mechanism to summarize multiple injuries into a single score was proposed.

This inability to summarize multiple injuries occurring in a single patient soon proved problematic and was addressed by Baker and colleagues in 1974 when they proposed the ISS. This score was defined as the sum of the squares of the highest AIS grade in each of the three (of six) most severely injured body areas:

$$\text{ISS} = (\text{highest AIS in worst area})^2 + (\text{highest AIS in second worst area})^2 + (\text{highest AIS in third worst area})^2$$

Because each injury was assigned an AIS severity from 1 to 6, the ISS could assume values from 0 (uninjured) to 75 (severest possible injury). A single AIS severity of 6 (fatal injury) resulted in an automatic ISS of 75. This scoring system was tested in a group of 2128 automobile accident victims. Baker and colleagues concluded that 49% of the variability in mortality rate was explained by this new score, a substantial improvement over the 25% explained by the previous approach of using the single worst-injury severity.

Both the AIS dictionary and the ISS have enjoyed considerable popularity over the past 30 years. The fifth revision of the AIS has recently been published and now includes over 2000 individual injury descriptors. Each injury in this dictionary is assigned a severity from 1 (slight) to 6 (unsurvivable), as well as a mapping to the Functional Capacity Index (a quality-of-life measure). The ISS has enjoyed even greater success—it is virtually the only summary measure of trauma in clinical or research use and has not been modified in the 30 years since its inception.

Despite their past success, both the AIS dictionary and the ISS have substantial shortcomings. The problems with AIS are twofold. First, the severities for each of the 2000 injuries are consensus derived from committees of experts and not simple measurements. Although this approach was necessary before large databases of injuries and outcomes were available, it is now possible to accurately measure the severity of injuries on the basis of actual outcomes. Such calculations are not trivial, however, because patients typically have more than a single injury, and untangling the effects of individual injuries is a significant mathematical exercise. Using measured severities for injuries would correct the inconsistent perceptions of severity of injury in various body regions first observed by Beverland and Rutherford and later confirmed by Copes et al. A second difficulty is that AIS scoring is expensive, and therefore is done only in hospitals with a zealous commitment to trauma. As a result, the experiences of most nontrauma center hospitals are excluded from academic discourse, thus making accurate demographic trauma data difficult to obtain.

The ISS has several undesirable features that result from its ad hoc conceptual underpinnings. First, because it depends on the AIS dictionary and severity scores, the ISS is heir to all the difficulties outlined previously. But the ISS is also intrinsically problematic in several ways. By design, regardless of how many injuries a patient may have sustained, the ISS allows a maximum of three injuries to contribute to the final score, but the actual number allowed is often fewer. Moreover, because the ISS allows only one injury per body region to be scored, the scored injuries are often not even the three most severe injuries. By considering less severe injuries, ignoring more severe injuries, and ignoring many injuries altogether, the ISS loses considerable information. Baker herself proposed a modification of the ISS, the new ISS (NISS), which was computed from the three worst injuries, regardless of the body region in which they occurred. Surprisingly, the NISS did not improve substantially upon the discrimination of ISS.

The ISS is also problematic mathematically. Although it is usually handled statistically as a continuous variable, the ISS can assume only integer values. Further, although its definition implies that the ISS can at least assume all integer values throughout its range of 0 to 75, because of its curious "sum-of-one (or two or three) squared integers" construction, many integer values can never occur. For example, 7 is not the sum of any three squares, and therefore can never be an ISS value. In fact, only 44 of the values in the range of ISS can be valid ISS values, and half of these are concentrated between 0 and 26. As a final curiosity, some ISS values are the result of one, two, or as many as 28 different AIS combinations. Overall, the ISS is perhaps better thought of as a procedure that maps the 84 possible combinations of three or fewer AIS injuries into 44 possible scores that are distributed between 0 and 75 in a nonuniform way.

The consequences of these idiosyncrasies for the ISS are severe, as an examination of the actual mortality rate for each of 44 ISS scores in a large data set (691,973 trauma patients contributed to the National Trauma Data Bank [NTDB]) demonstrates. Mortality does not increase smoothly with increasing ISS, and more troublingly, for many pairs of ISS scores, the higher score is actually associated with a lower mortality rate (Fig. e2A and B). Some of these disparities are striking: patients with ISS values of 27 are four times *less* likely to die than patients with ISS values of 25. This anomaly occurs because the injury subscore combinations that result in an ISS of 25 (5,0,0 and 4,3,0) are, on average, more likely to be fatal than the injury subscore combinations that result in an ISS of 27 (5,1,1 and 3,3,3). (Kilgo et al. note that 25% of ISSs can actually be the result of two different subscore combinations, and that these subscore combinations usually have mortality rates that differ by over 20%.)

Despite these problems, the ISS has remained the preeminent scoring system for trauma. In part this is because it is widely recognized, easily calculated, and provides a rough ordering of severity that has proved useful to researchers. Moreover, the ISS does powerfully separate survivors from nonsurvivors, as matched histograms of ISS for survivors and fatalities in the NTDB demonstrate (see Fig. e1B), with an ROC of 0.86.

The idiosyncrasies of ISS have prompted investigators to seek better and more convenient summary measures of injury. Champion and coworkers attempted to address some of the shortcomings of ISS in 1990 with the Anatomic Profile (AP), later modified to become the modified AP (mAP). The AP used the AIS dictionary of injuries, and assigned all AIS values greater than 2 to one of three newly defined body regions (head/brain/spinal, thorax/neck, other). Injuries were combined within body region using a Pythagorean distance model, and these values were then combined as a weighted sum. Although the discrimination of the AP and mAP improved upon the ISS, this success was purchased at the cost of substantially more complicated calculations, and the AP and mAP have not seen wide use.

Osler and coworkers in 1996 developed an injury score based upon the ICD-9 lexicon of possible injuries. Dubbed ICISS (ICD-9 Injury Severity Score), the score was defined as the product of the individual probabilities of survival for each injury a patient sustained:

$$\begin{aligned}\text{ICISS} = (\text{SRR})_{\text{Injury 1}} \times (\text{SRR})_{\text{Injury 2}} \times (\text{SRR})_{\text{Injury 3}} \times \ldots \\ \times (\text{SRR})_{\text{Injury Last}}\end{aligned}$$

where SRR = survival risk ratio.

These empiric survival risk ratios were in turn calculated from a large trauma database. ICISS was thus by definition a continuous predictor bounded between 0 and 1. ICISS provided better discrimination between survivors and nonsurvivors than did ISS, and also proved better behaved mathematically. The probability of death uniformly decreases as ICISS increases (see Fig. e1A), and ICISS powerfully separates survivors from nonsurvivors (see Fig. e1C). A further advantage of the ICISS is that it can be calculated from administrative hospital discharge data, and thus the time and expense of AIS coding are avoided. This coding convenience has the salutary effect of allowing the calculation of ICISS from administrative data sets, and thus allows injury severity scoring for all hospitals. A score similar to ICISS but based on the AIS lexicon, Trauma Registry Abbreviated Injury Scale (TRAIS), has been described and has a performance similar to that of ICISS. Because ICISS and TRAIS share a common structure, it is likely that they will allow comparisons to be made between data sets described in the two available injury lexicons, AIS and ICD-9.

Other ICD-9-based scoring schemes have been developed that first map ICD-9 descriptors into the AIS lexicon, and then calculate AIS-based scores (such as ISS or AP). In general, power is lost with such mappings because they are necessarily imprecise, and thus this approach is only warranted when AIS-based scores are needed but only ICD-9 descriptors are available.

Many other scores have been created. Perhaps the simplest was suggested by Kilgo and coworkers, who noted that the survival risk ratio for the single worst injury was a better predictor of fatality than several other models they considered that used all the available injuries. This observation is very interesting because it seems unlikely that ignoring injuries should improve a model's performance. Rather, Kilgo's observation seems to imply that most trauma scores are miss-specified; that is, they use the information present in the data suboptimally. Much more complex models, some based on exotic mathematical approaches such as neural networks and classification and regression trees, have also been advocated but have failed to improve the accuracy of predictions.

To evaluate the performance of various anatomic injury models, their discrimination and calibration must be compared using a

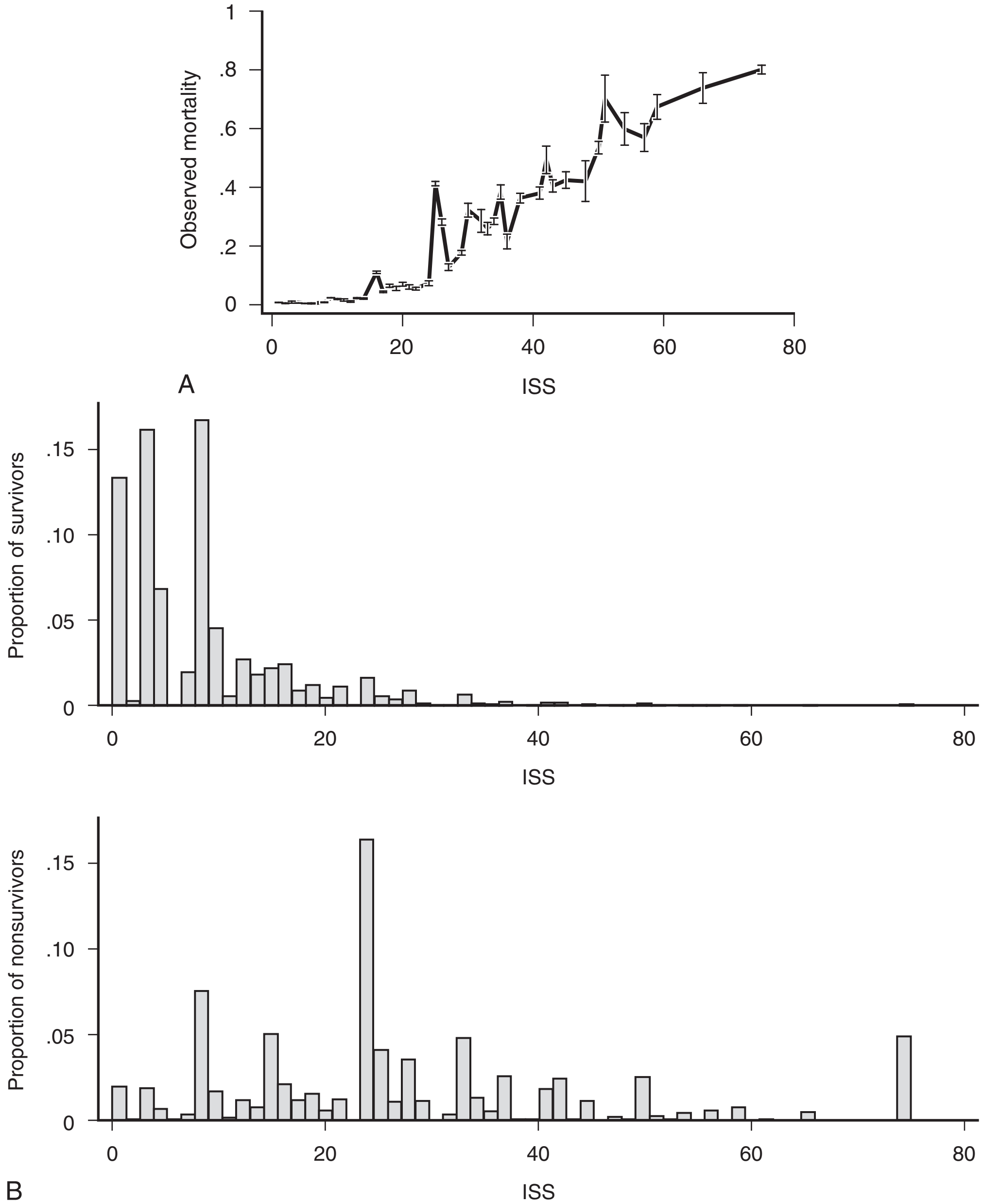

FIGURE E2 **A,** Survival as a function of Injury Severity Score (ISS). One half of valid ISS values are below 25 due to the sum of squares definition of ISS. Because the data set is spread over 44 ISS values, and higher scores occur less often, error bars for higher ISS values are wider than for lower ISS values (691,973 patients from the National Trauma Data Bank [NTDB]). **B,** ISS presented as paired histograms of survivors *(above)* and nonsurvivors *(below)*. Note that only the 44 possible ISS values are represented. In general, survivors tend to have lower ISS values. Some ISS values are dramatically more common, in part because these scores result from two or more combinations of AIS severity scores (691,973 patients from the NTDB).

common data set. The largest such study was performed by Meredith et al., who evaluated nine scoring algorithms using the 76,871 patients then available in the NTDB. Performance of the ICISS and AP were found to be similar, although ICISS better discriminated survivors from nonsurvivors, and the AP was better calibrated. Both of these more modern scores dominated the older ISS, however. Meredith and colleagues concluded that "ICISS and APS provide improvement in discrimination relative to . . . ISS. Trauma registries should move to include ICISS and the APS. . . . The ISS performed moderately well and [has] bedside benefits."

Because both ICD-9 and AIS continue to be used to describe traumatic injuries, a scoring approach that can produce predictions based on either lexicon seems desirable. Only one such model is currently available, the Trauma Mortality Prediction Model (TMPM), but in the future this may be an important characteristic of all outcome prediction models.

MEASURING PHYSIOLOGIC INJURY

Accurate outcome prediction depends on more than simply reliable anatomic injury severity scoring. If we imagine two patients with identical injuries (e.g., four contiguous comminuted rib fractures and underlying pulmonary contusion), we would predict an equal probability of survival until we are informed that one patient is breathing room air comfortably while the other is dyspneic on a

100% O_2 rebreathing mask and has a respiratory rate of 55. Although the latter patient is not certain to die, his chances of survival are certainly lower than those of the patient with a normal respiratory rate. Although obvious in clinical practice, quantification of physiologic derangement has been challenging.

Basic physiologic measures such as blood pressure and pulse have long been important in the evaluation of trauma victims. More recently, the Glasgow Coma Scale (GCS) has been added to the routine trauma physical examination (Fig. e3A). Originally conceived over 30 years ago as measure of the "depth and duration of impaired consciousness and coma," the GCS is defined as the sum of coded values that describe a patient's motor (1–6), verbal (1–5), and eye (1–4) levels of response to speech or pain. As defined, the GCS can take on values from 3 (unresponsive) to 15 (unimpaired). Unfortunately, simply summing these components obscures the fact that the GCS is actually the result of mapping the 120 different possible combinations of motor, eye, and verbal responses into 12 different scores. The result is a curious triphasic score in which scores of 7, 8, 9, 10, and 11 have identical mortality probabilities. Fortunately, almost all of the predictive power of the GCS is present in its motor component, which has a very nearly linear relationship to survival (Fig. e3B and C). It is likely that the motor component alone could replace the GCS with little or no loss of performance, and it has the clear advantage that such a score could be calculated for intubated patients, something not possible with the three-component GCS because of its reliance on verbal response. Despite these imperfections, the GCS remains part of the trauma physical examination, perhaps because as a measure of brain *function*, the GCS assesses much more than simply the anatomic integrity of the brain. Figure e3B shows that GCS powerfully separates survivors from nonsurvivors.

Currently, the most popular measure of overall physiologic derangement is the RTS. It has evolved over the past 30 years from the Trauma Index, through the Trauma Score to the RTS in common use today. The RTS is defined as a weighted sum of coded values for each of three physiologic measures: GCS, systolic blood pressure (SBP), and respiratory rate (RR). Coding categories for the raw values were selected on the basis of clinical convention and intuition (Table e1). Weights for the coded values were calculated using a logistic regression model and the Multiple Trauma Outcome Study (MTOS) data set. The RTS can take on 125 possible values between 0 and 7.84:

$$RTS = 0.9368\, GCS_{Coded} + 0.7326\, SBP_{Coded} + 0.2908\, RR_{Coded}$$

Even though the RTS is in common use, it has many shortcomings. As a triage tool, the RTS adds nothing to the vital signs and brief neurologic examination because most clinicians can evaluate vital signs without mathematical "preprocessing." As a statistical tool, the RTS is problematic because its additive structure simply maps the 125 possible combinations of subscores into a curious, nonmonotonic survival function (Fig. e4A). Finally, the reliance of RTS on the GCS score makes its calculation for intubated patients problematic. Despite these difficulties, the RTS discriminates survivors from nonsurvivors surprisingly well (Fig. e4B). Nevertheless, it is likely that a more rigorous mathematical approach to an overall measure of physiologic derangement would lead to an improved score. Such a modification was recently proposed that relies solely upon SBP and the motor component of the GCS.

MEASURING PHYSIOLOGIC RESERVE AND COMORBIDITY RISK

Physiologic reserve is an intuitively simple concept that, in practice, has proved elusive. In the past, age has been used as a surrogate for physiologic reserve, and although this expedient has improved prediction slightly, age alone is a poor predictor of outcome. Using the example of two patients with four contiguous comminuted rib fractures and underlying pulmonary contusion, we would predict equal likelihood of survival until we are told that one patient is a 56-year-old triathlete, and the other is a 54-year-old with liver cirrhosis who is awaiting liver transplant and is taking steroids for chronic obstructive pulmonary disease (COPD). Although the latter patient is not certain to die, his situation is certainly more precarious than that of the triathlete. Remarkably, the TRISS method of overall survival prediction (see later) would predict that the triathlete is more likely to die. Although this scenario is contrived, it underscores the failure of age as a global measure of patient reserve. Not only does age fail to discriminate between "successful" and "unsuccessful" aging, it ignores comorbid conditions. Moreover, the actual effect of age is not a binary function as it is modeled in TRISS and is probably not linear either.

Although physiologic reserve depends on more than age, it is difficult to define, measure, and model the other factors that might be pertinent. Certainly, compromised organ function may contribute to death following injury. Morris et al. determined that liver cirrhosis, COPD, diabetes, congenital coagulopathy, and congenital heart disease were particularly detrimental following injury. Although many other such conditions are likely to contribute to outcome, the exact contribution of each condition will likely depend on the severity of the particular comorbidity in question. Because many of these illnesses will not be common in trauma populations, constructing the needed models may be difficult. Although the Deyo-Charlson scale has been used in other contexts, it is at best an interim solution, with some researchers reporting no advantage to including it in trauma survival models. As yet, no general model for physiologic reserve following trauma is available.

MORE POWERFUL PREDICTIONS: COMBINING SEVERAL TYPES OF INFORMATION

The predictive power of models is usually improved by adding more relevant information and more relevant types of information into the model. This was recognized by Champion et al. in 1981, as they combined the available measures of injury (ISS), physiologic derangement (RTS), patient reserve (age as a binary variable: age $>$ 55 or age $<$ 56), and injury mechanism (blunt/penetrating) into a single logistic regression model. Coefficients for this model were derived from the MTOS data set. Called TRISS (TRauma score, Injury Severity Score age comorbidity index), this score was rapidly adopted and became the de facto standard for outcome prediction. Unfortunately, as was subsequently pointed out by its developers and others, TRISS had only mediocre predictive power and was poorly calibrated. This is not surprising, because TRISS is simply the logit transformation of the weighted sum of three subscores (ISS, RTS, GCS), which are themselves poorly calibrated and, in fact, not even monotonically related to survival. Because of this "sum of subscores" construction, TRISS is heir to the mathematically troubled behavior of its constituent subscores, and, as a result, TRISS is itself not monotonically related to survival (Fig. e5A). Although TRISS was conceived in hopes of comparing the performance of different trauma centers, the performance of TRISS has varied greatly when it was used to evaluate trauma care in other centers and other countries, suggesting that either the standard of trauma care varied greatly or, more likely, that the predictive power of TRISS was greatly affected by variation in patient characteristics ("patient mix"). Still another shortcoming is that because TRISS is based on a single data set (MTOS), its coefficients were "frozen in time," in the sense that the predictions of the TRISS model reflect the success rate of trauma care 20 years ago. When new coefficients are calculated for the TRISS model, predictions improve, but it is unclear how often such coefficients should be recalculated, or what data set they should be based on. Thus, as a tool for comparing trauma care at different centers, TRISS seems fatally deficient.

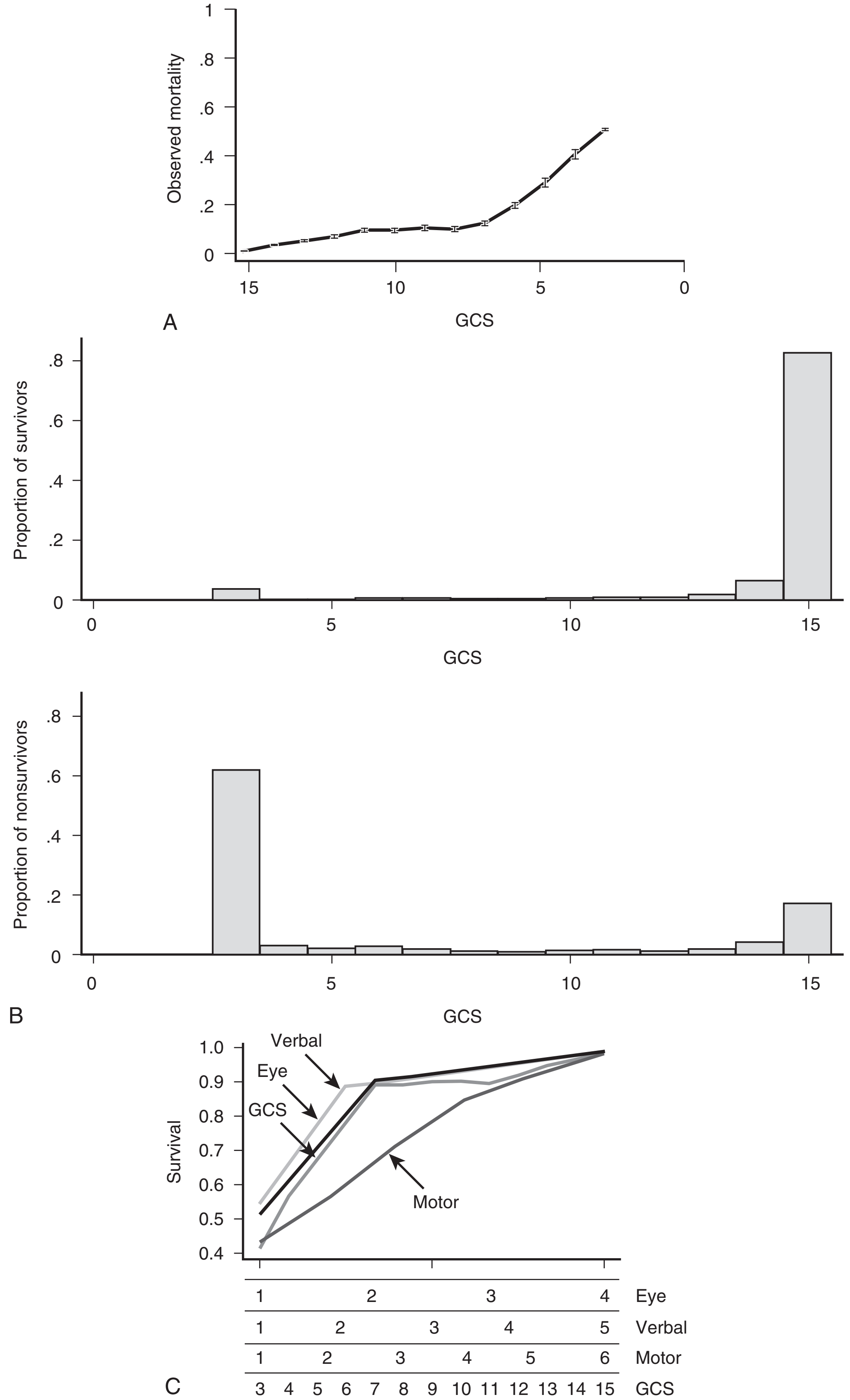

FIGURE E3 **A,** Survival as a function of Glasgow Coma Scale (GCS) score (691,973 patients from the National Trauma Data Bank [NTDB]). **B,** GCS scores presented as paired histograms of survivors *(above)* and nonsurvivors *(below)* (691,973 patients from the NTDB). **C,** GCS scores (691,973 patients from the NTDB). Note that the eye and verbal subscores are not linear, and as a result the summed GCS score is also nonlinear. The motor score, by contrast, is quite linear.