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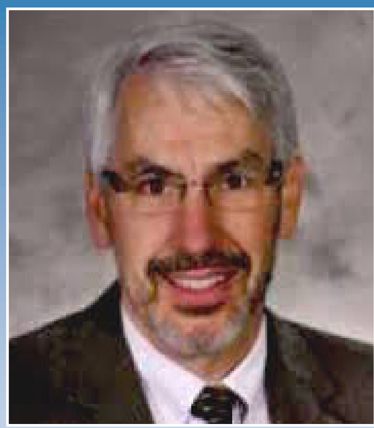

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SPECIAL SECTION

UPDATES IN TRAUMA CARE

GUEST EDITORS: CHARLES A. ADAMS, JR, MD, FACS, FCCM; STEPHANIE N. LUECKEL, MD, ScM, FACS

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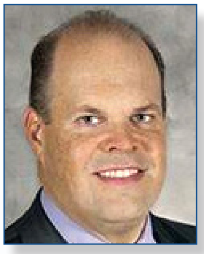
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Trauma Surgery and Acute Care Surgery: Evolution in the Eye of the Storm

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GUEST EDITORS

Once again, I have the honor to introduce this month's edition of the *Rhode Island Medical Journal* focusing on trauma surgery. Ten years ago,[1] in an article entitled "Care of the Trauma Patient: A Discipline in Flux," I wrote briefly of the developments affecting the management of injured patients as well as those who care for them. Since that time, the evolution of trauma surgery to Acute Care Surgery (ACS) continues and the ACS "model" has become the standard care model in most of the United States. The genesis of ACS is multifactorial and reflects a confluence of several external forces on the practice of trauma surgery.[2] As imaging technology and risk-stratified outcomes data became more refined, trauma surgery shifted away from routine operative interventions to treat most injuries to a more selective operative approach incorporating non-operative management (NOM). NOM was borrowed from pediatric surgeons who long ago established that children with some solid organ injuries, such as splenic lacerations, could be safely and effectively managed without surgical intervention.

Advances in medical imaging enabled trauma surgeons to better identify injuries and define populations of trauma patients who are appropriate for NOM.[3] Non-invasive CT angiography has by and large supplanted invasive angiography in the diagnosis of occult vascular injuries. Formal angiography is generally reserved for those patients in whom embolization will be necessary, particularly in cases of known solid organ injury where NOM is being attempted. Detailed risk-adjusted databases such as the Trauma Quality Improvement Program (TQIP) allow trauma surgeons to formulate data-driven treatment plans incorporating sophisticated outcomes data, which eliminates some of the uncertainty and variability that trauma surgeons routinely encounter.[4] TQIP is an essential component of trauma center verification and participation in the program is mandated by the American College of Surgeons (ACS), the national organization that accredits trauma centers. Unlike many administrative databases in healthcare, TQIP and several other surgical databases such as the National Surgical Quality Improvement Project (NSQIP) database, are risk-adjusted so that like patients can be compared across participating centers. These high-quality, risk-adjusted databases serve as the engine to drive quality improvement. The ongoing commitment to quality improvement attests to the fact that surgeons began the "quality movement" in healthcare more than 150 years ago. At that time, Codman established his "end result system" that tracked patient outcomes as well as oversaw the first mortality and morbidity conferences, thus incorporating quality improvement into the practice of surgery.[5,6] Continuous quality improvement has been a vital function of the ACS Committee on Trauma for more than 60 years and it is often forgotten that the ACS helped create the Joint Commission on Accreditation of Hospitals.

One of the unintended consequences of NOM was that trauma surgery moved from a very operative profession to a more non-operative one, which lead to an erosion of some of the surgical abilities of surgeons caring for trauma patients. Coincident with this development were changes in the practice of surgery with an explosion in sub-specialization, and less "old school" general surgeons, that adversely affected the ability of hospitals to staff their on-call schedules. Since all trauma surgeons are board-certified general surgeons, they quickly expanded their role to fill the void and many of them incorporated emergency general surgery into their daily practice. The majority of trauma surgeons are double-boarded in critical care, which empowers them to care for the sickest surgical patients, whereas some general surgeons may be hesitant to operate on critically ill patients. The incorporation of emergency general surgery into trauma surgery allowed many institutions to round out their call schedule and ensured that trauma surgeons maintained their sharp operative edge while also maximizing their clinical productivity. The burgeoning ACS movement became more solidified and had at its core three disparate but interrelated disciplines: trauma surgery, surgical critical care and emergency general surgery.

During the transformation of trauma surgery into ACS, a similar evolution affected surgical training of both general surgery residents and critical care fellows. The American Council for Graduate Medical Education (ACGME) duty-hour changes of 2003 had unintended adverse effects on the training and ability of general surgery residents to treat many common surgical emergencies that were formerly in the domain of general surgeons.[7] It became apparent that most graduating chief residents, particularly those choosing trauma surgery as their career, required additional training in emergency general surgery. By design, most surgical critical care fellowships are heavily focused on intensive care medicine, and while there are some opportunities for operative rotations and experience, this was not enough to address the growing deficiencies in graduating surgical chief residents. To fill this gap in training, many surgical critical care fellowships added an additional year of training beyond the ACGME-approved year in critical care training. This additional year was focused on trauma and emergency general surgery and grew into Acute Care Surgery fellowships. These fellowships include advanced surgical training in vascular, thoracic, and hepatobiliary surgery to round out some of the perceived weaknesses in graduating chief surgical residents, as well as to prepare ACS fellows to practice as fully capable trauma surgeons. The governing body of these ACS fellowships was not the ACGME but rather the American Association for the Surgery of Trauma (AAST), which is the premier academic society of trauma surgery. Like ACGME accreditation, AAST accreditation of ACS fellowships requires a diverse didactic curriculum addressing traumatic and general surgery emergencies, in-service examinations, case logs, requirements for scholarly activity as well as continued re-verification of ACS fellowship programs through a rigorous review process incorporating site visits by teams of experienced reviewers.

Presently, most chief surgical residents choosing a career in trauma seek an additional two years of training in ACGME-approved critical care residencies and AAST-approved ACS fellowships, which renders them well versed in treating a wide range of surgical patients.[8] The initial iteration of ACS fellowships sought to address some of the problems that institutions experienced as previously discussed, namely the lack of physicians willing or able to take call due to sub-specialization, fear of medico-legal liability, or simply being spread too thin and overworked. The founders of ACS envisioned that ACS surgeons would fill some of that void through training in basic orthopedic and neurosurgical interventions; however, this never came to fruition due to resistance of the governing bodies of those respective disciplines, as well as fear of litigation and concerns about maintaining competency for low-volume, high-risk interventions. Now, many trauma centers and ACS surgeons perceive a lack of clinical support from vascular surgeons as vascular fellowship training has steadily moved toward endovascular approaches. Consequently, experience in open vascular surgery becomes much less common in general surgery residencies as well as in vascular fellowships.[9] Unfortunately, few traumatic vascular injuries are amenable to endovascular approaches, especially when the patient is hemodynamically unstable, so most require open operative repair. This may create the uncomfortable scenario where the vascular consultant may have less experience in treating the major vascular injury than the ACS surgeon requesting their assistance. Some trauma centers have sent fully trained ACS surgeons for formal training in vascular surgery so that they may serve as the continual in-house consultant to the ACS surgeons, but this is cost and time prohibitive. Based on similar needs in the past, it is possible that ACS fellowships may incorporate an additional year of training dedicated to vascular surgery, which, in effect, will require a three-year time commitment following a general surgery residency. While it is hard to argue against duty-hour restrictions from the point of the trainee's quality of life and wellbeing, it is apparent that there have been some unintended and adverse effects on the quality of surgical education and training.

Perhaps no recent development has changed the practice of trauma and ACS more than the aging of the US population. Injury is the 7th leading cause of death for patients > 65 years.[10] A tide of aging Baby Boomers has inundated most trauma centers across the US. The leading trauma mechanism requiring admission has shifted from interpersonal violence and motor vehicle collisions to falls. Most of these are falls from standing. The unique aspects of caring for geriatric patients are discussed by **DR. ERIC BENOIT**, et al, in his article, "Geriatric Trauma." Rhode Island is no exception; in fact, the Rhode Island Trauma Center (RITC) at Rhode Island Hospital has one of the highest average trauma admission ages in the US at 61.3 years. In 2018, the RITC admitted 1,000 patients over the age of 80, and 353 of these patients were 90 years old or older. In response to this development, the trauma service has a collaborating geriatrician who is part of the trauma team and is an invaluable resource in the care of these patients. Once again, trauma surgeons have to adapt in response to new realities. End-of-life care has taken on huge importance in the practice of trauma and emergency general surgery. Unfortunately, very few elderly trauma patients arrive at the RITC with advanced directives. Families often state that this issue has never come up, which represents an immense opportunity for primary care physicians to reduce unnecessary care, suffering and health care expenditures.

The concept of frailty is paramount in the care of elderly patients. Recent studies demonstrate that frailty is far more important to outcomes than chronologic age.[11] Admission of geriatric patients to the trauma service is now an opportunity to assess frailty and reconsider prophylactic therapies such as anti-coagulation or anti-platelet therapies, as well as living arrangements and the need for additional resources for these patients. Often, anti-platelet or anticoagulants are discontinued in frail patients and thoughtful risk-to-benefit analysis of these therapies is best conducted in the ambulatory setting after the patient has partially recovered from the effects of injury and hospitalization. The number of approved novel anticoagulants and anti-platelet agents coming to market occurs at a dizzying pace and it can be difficult for trauma surgeons, and many other physicians, to keep abreast of these agents. **DR. ANDREW STEPHEN**, et al, reviews these agents and their impact on the care of injured patients in the article, "Anticoagulation and Trauma."

Many blunt trauma patients, particularly the elderly, are susceptible to rib fractures. The RITC admits nearly 1,000 patients annually with rib fractures, which speaks to the fact that the RITC is a primarily a geriatric and blunt trauma center. Advances in radiographic imaging, particularly three-dimensional reconstructions of the chest, allow the trauma surgeon to fully visualize fracture patterns as well as estimate loss of thoracic volume, etc. and are invaluable in preoperative planning for chest-wall stabilization or rib "plating." Rib plating represents an advance in technology that unites better radiographic data with open reduction and internal fixation techniques borrowed from orthopedic surgery. The indications for rib plating are still being elucidated but include flail chest, crushed chest, loss of volume, intractable pain, and pulmonary embarrassment. Rib fractures are particularly deadly in the elderly and their sequelae are often misdiagnosed as pneumonia by providers not well versed in their management. The RITC employs a multi-modality, multi-disciplinary approach toward managing these injuries, including intensive care admission for geriatric patients with blunt chest trauma. This approach has paid dividends with lower than expected mortality.[12] **DR. MICHAEL CONNOLLY**, et al, reviews the management of patients with thoracic trauma and rib fractures in the article, "Practice Makes Perfect: The Evolution of Blunt Chest Trauma."

Advances in technology are also opening new avenues for hemorrhage control, which is critically important since exsanguination remains the leading cause of death following traumatic injury. Retrograde endovascular balloon occlusion of the aorta or REBOA, has emerged as a rapid, bedside approach to temporize intra-abdominal or pelvic hemorrhage. REBOA is performed by trauma surgeons percutaneously at the bedside and can buy time while resources are mobilized to undertake operative or angiographic intervention. Tourniquets have transitioned from the battlefield into every day civilian life as have other hemorrhage control adjuncts such as hemostatic gauzes and topical agents. Damage control surgery, one of the major advances in trauma surgery of the last few decades, is now accompanied by damage control resuscitation developed and refined on the battlefields of Iraq and Afghanistan. This new approach to hemorrhage control and resuscitation is reducing trauma mortality rates across the United States and worldwide. **DR. TAREQ KHEIRBEK**, et al, discusses some of these new approaches in the article, "Advances in the Management of Bleeding Trauma Patients."

Trauma surgery and critical care medicine are experiencing a bit of an existential crisis as clinicians are asking not how to care for critically ill and injured patients, but rather should we treat them at all. The basis for these questions is the emergence of long-term outcome data highlighting the often dismal and devastating effects of the Post-Intensive Care Syndrome (PICS). PICS can leave lifelong cognitive, physical, psychological and social deficits after critical illness, especially sepsis.[13] This area remains a hotbed of research and debate. **DR. STEPHANIE LUECKEL**, et al, touches upon this controversial topic, focusing on Traumatic Brain Injury (TBI) outcomes in the article, "Predicting Outcomes in Acute Traumatic Brain Injury (TBI)."

Trauma surgery continues to evolve in response to a multitude of external and internal forces. Care continues to become more complex and challenging as technology and big data affords new opportunities to intervene. However, we must never lose sight of the dedicated professionals who devote themselves to the care of injured patients and hopefully we will reduce the burden of trauma, the number one killer of Americans aged 1 to 45.

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Geriatric Trauma

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STEPHANIE N. LUECKEL, MD, ScM, FACS; CHARLES A. ADAMS, JR., MD, FACS, FCCM

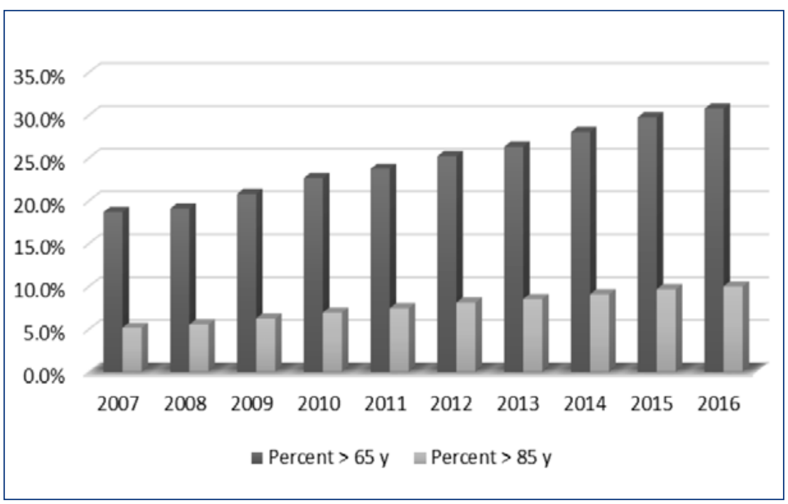
INTRODUCTION

The incidence of trauma in the elderly is increasing. Older patients are less able to tolerate injury due to physiologic alterations associated with aging. Clinicians need to approach geriatric trauma with a high degree of suspicion to promptly recognize and treat injuries and rescue patients from their initial injury and its potential complications.

EPIDEMIOLOGY

Trauma is considered a young person's disease, but the aging of the population is changing that reality. People over 65 are the fastest growing demographic, and by 2020 they will comprise over 20% of the US population.[1] People are living longer, and many of them lead active lifestyles which increase their exposure to trauma. Conversely, a greater proportion of elderly people are living with comorbidities, and this increases their vulnerability to injury. The net effect is an increase in elderly trauma patients, and this is reflected in the proportion of patients over 65 admitted to trauma centers. (**Figure 1**) At the Rhode Island Trauma Center (RITC) at Rhode Island Hospital, the mean age of admitted trauma patients has increased from 50.9 to 61.3 years over the past decade. The cost of trauma care is rising faster than overall healthcare spending, and much of this is driven by the expansion of geriatric trauma in terms of numbers, complexity and resource use.[2]

Figure 1. Geriatric admissions to trauma centers 2007–2016



The percentage of geriatric patients as a fraction of all trauma admissions has increased from 18.7% in 2007 to 30.8% in 2016. Data derived from National Trauma Data Bank (NTDB) annual reports. Committee on Trauma, American College of Surgeons. Chicago, IL. https://www.facs.org/quality-programs/trauma/tqp/center-programs/ntdb/docpub

TRIAGE & TRAUMA CENTERS

The Eastern Association for the Surgery of Trauma (EAST) guidelines recommend that patients over 65 years of age with comorbidities or severe anatomic injury should be treated at trauma centers. Centers that treat a higher volume of geriatric patients have improved outcomes with regard to mortality, complications, and failure to rescue (FTR), defined as death after a complication.[3] However, fewer than 50% of patients are appropriately transferred to a higher level of care, and the risk of under-triage increases with age, fall mechanisms, and female gender.[4] This under-triage reflects a failure to appreciate the severity of even minor injury in elderly patients, and contributes to the fact that elderly trauma patients have worse outcomes than younger patients with the same degree of injury. Because early activation of trauma teams and aggressive monitoring improve outcomes in elderly patients, clinicians should have a low threshold to transfer older patients to a trauma center. There are very few "minor" injuries in geriatric patients.

ALTERED PHYSIOLOGY

The numerous physiologic changes associated with aging along with co-morbidities complicate the recognition of injury severity, compromise the body's response to trauma, and predispose to the development of complications. Elderly patients have decreased muscle mass, chest wall recoil, and cough strength, all of which contribute to increased risks of aspiration, atelectasis and pneumonia after injury, regardless of the site of trauma.

The impact of aging on the cardiovascular system is profound in the trauma patient. The heart stiffens with age, resulting in diastolic dysfunction. Older patients exhibit a blunted chronotropic response that may be exacerbated by pharmacologic beta blockade or other rate controlling agents. These patients cannot augment cardiac output and instead compensate for hemorrhagic shock by increasing systemic vascular resistance. Vital signs that are interpreted as normal in young patients may reflect relative hypotension and decreased end organ perfusion in the elderly, particularly in those with baseline hypertension. Whereas hypotension is defined <90 in younger trauma patients, systolic blood pressures <110 are associated with increased mortality in the elderly trauma patient.[5] This is particularly important in solid organ injuries where episodes of hypotension predict failure of non-operative management.

When assessing older trauma patients with altered mental status, it is challenging to determine if neurologic deficits are due to injury, pharmacologic agents, or baseline cognitive dysfunction. This may delay prompt recognition of injury or complications. Elderly patients are at increased risk of delirium and the high mortality associated with this complication.

Renal cell mass is lost with age, leading to decreased glomerular filtration rate which complicates pharmacokinetics, increases the risk of acute kidney injury (AKI) and impairs recovery to baseline renal function. Urinary tract infections (UTI) are a risk factor for trauma, particularly falls. A study of elderly trauma patients identified 11% with UTI on admission and a further 18% with asymptomatic bacteria.[6] The development of UTI after trauma admission is associated with mortality and this risk increases with increasing age.[7]

The proliferation of anticoagulation for arrhythmias and thromboembolic disease has resulted in an increasing number of elderly patients presenting with coagulopathy. Practitioners should be alert for occult bleeding, particularly within closed compartments like the skull, and clinicians must consider prophylactic pharmacologic reversal prior to obtaining CT in geriatric trauma patients.

Finally, due to impaired thermoregulation, elderly patients may present with hypothermia despite being found indoors. While the degree of temperature derangement is not as profound as with environmental exposure, hypothermia complicates and worsens outcomes from trauma in elderly patients.[8]

COMORBIDITIES & FRAILTY

Three of four people over 65 have at least one chronic illness, and the number of comorbidities rises with age.[9] Recent work in emergency general surgery demonstrates that certain combinations are more lethal than others. Hypertension, arrhythmias and fluid & electrolyte (FEN) disorders are the most common and increase with age whereas coagulopathy & FEN disorders confer the highest increased mortality risk.[10] Elderly trauma patients cannot be managed without considering their chronic diseases and socioeconomic features contributing to their disability.[11]

The physiologic changes associated with aging and comorbidities are not equally distributed by age. Frailty is a concept that captures physiologic decline better than numeric age alone. Defined as a condition of decreased physiologic reserve and impaired ability to respond to stressors, frailty is both a risk factor for – and a predictor of – poor outcomes. Frail elderly trauma patients have a 25% mortality one year after injury; they are more likely to develop complications and require a prolonged length of stay or discharge to a facility.[12] Because they lack the physiologic robustness to tolerate a complication, frail patients have higher rates of failure to rescue.[13] Recognizing frailty in the elderly trauma population is critical because it allows clinicians to identify patients at high risk of adverse outcomes, intervene promptly, and achieve rescue. It may also play a role in determining futility of care.

There are multiple instruments used to calculate frailty, but there is no consensus on which model is best used across various clinical settings.[14] Although the initial frailty index consisted of 50 preadmission variables, the modified frailty index (mFI) employs 11, including a measure of functional status. Patients who are dependent prior to injury have a worse prognosis with increased postoperative complication rates and mortality compared to independent patients. The mFI has been used to identify high risk elderly trauma patients.[15] To guide conversations with patients and families regarding prognosis and to assist in determining futility, Zhao et al developed a geriatric trauma outcome score consisting of age, injury severity score (ISS) and need for blood transfusion, which predicts risk of hospital mortality.[16] Comorbidities, frailty and the geriatric trauma outcome score can be incorporated into the decision-making process with older trauma patients.

MECHANISM OF INJURY

Ground level falls are the most common mechanism of injury among all trauma patients, and this is driven by the overwhelming number of elderly patients; greater than 1 in 4 elderly people fall each year.[17] The risk of fall increases with impaired mobility, altered sensorium, medication effects, and recent hospitalizations, all of which are prevalent in the older population. Falls are a risk factor for future falls and frequently herald a patient's physiologic decline and loss of independence. Despite the low energy mechanism, mortality may be as high at 7% for falls requiring admission, and only 50% of these patients are alive at one year.[9]

Motor vehicle crashes are common in elderly patients, with the risk of fatal collision rising with age. As the number of elderly drivers increases, we can anticipate more injuries.[14] The elderly are also at risk of being struck as pedestrians. In New York City patients 65 years and older comprise 1/3 of all pedestrian deaths.[18]

Other causes of injury in the older population include suicide and abuse. The overall incidence of suicide is higher in the elderly than in the general population. Nearly three quarters are due to firearms, which carry a high mortality.[19] The functionally dependent status of many elderly patients puts them at risk for abuse. While this may present as assault, abuse also takes the form of neglect, with patients found emaciated or dehydrated. Identifying abuse often requires a high level of suspicion.

PATTERNS OF INJURY

Several common injury patterns warrant special attention in the elderly.

Rib fractures

While rib fractures may be well tolerated in younger patients, as few as two rib fractures in the elderly increases the risk of pneumonia and mortality, and the risk rises with the number of fractures. Pain leads to chest wall splinting, decreased alveolar recruitment, and impaired cough which may progress to pneumonia. Rib fracture management is based on multimodal pain control and aggressive pulmonary toilet. Narcotics have a narrow therapeutic window in the elderly with somnolence and respiratory depression worsening pulmonary toilet. Acetaminophen, gabapentin and pregabalin can improve pain control while minimizing narcotics or the nephrotoxic non-steroidal anti-inflammatories (NSAIDs). Local analgesia with epidural or erector spinae blocks augment pharmacologic pain control. Pulmonary toilet consists of induced coughing, incentive spirometry or flutter valve devices to improve alveolar recruitment, and early mobilization. Aggressive pulmonary toilet and multimodal analgesia are resource-intensive therapies, but they improve outcomes. Our institution adopted a protocol whereby all patients over 65 years with 2 or more rib fractures are admitted to our trauma ICU. We observed improved outcomes with decreased need for intubation (43% to 14%) and decreased mortality (24% to 9%).

Hip & Pelvic fractures

Hip fractures in the elderly have a 30% one-year mortality. Early repair of these fractures is warranted as delays beyond 48 hours are associated with increased risk of death.[20] Ironically, attempting to optimize medical status prior to operation may instead deplete physiologic reserves and worsen outcomes. Elderly patients have a high incidence of pelvic fractures, and even minor injury patterns may precipitate bleeding. Pelvic hematomas may be out of proportion to the severity of fractures due to poor tissue integrity with loss of tamponade effect as well as the prevalence of anticoagulation. Clinicians should have a low threshold to obtain CT imaging, reverse anticoagulation, and pursue interventional radiology to address active bleeding. Pelvic fractures in the elderly are best managed in trauma centers.

Traumatic brain injury

It is difficult to differentiate chronic cognitive decline from acute altered mental state due to trauma in an elderly patient; thus, a high level of suspicion is mandatory. Cortical atrophy develops with age, increasing the risk of bridging vessel rupture and intracranial bleeding from even minor mechanisms; anticoagulation increases the risk of intracranial hemorrhage as much as 7–10 fold. [21] As with pelvic fractures, clinicians should have a low threshold to reverse anticoagulation, even prior to imaging.

OUTCOMES & GOALS OF CARE

While all trauma patients are at risk for developing complications, elderly trauma patients are more likely to develop these adverse events and less likely to tolerate them. Failure to rescue from complications is one reason for higher mortality in elderly trauma patients. For those patients who do survive, the traumatic injury may be a sentinel event that precipitates a loss of function and independence. Patients who deplete their physiologic reserve during recovery may fail to achieve their pre-injury functional status and progress to a chronic disease state.[12]

Despite the challenges of managing elderly trauma patients, there need not be therapeutic nihilism – we can have a positive impact. It is important to recognize outcomes beyond mortality that are valuable to patients and families. Identifying goals of care early in the hospital course includes setting realistic expectations regarding prolonged recovery, anticipated complications, and potential loss of function or independence. Geriatric and palliative care specialists play an important role in caring for trauma patients. Geriatric medicine specialists can optimize management of comorbidities and medications, and the implementation of a multidisciplinary team approach has demonstrated improved outcomes in frail elderly trauma patients.[22] Early involvement of palliative care services improve clinician and family consensus around goals of care. Palliative care is associated with decreased health care utilization by trauma patients at the end of life.[23]

CONCLUSIONS

The incidence of elderly trauma is increasing. Severity of injury may be underappreciated in elderly patients due to low energy mechanisms, injury patterns and blunted physiologic response to injury, resulting in under-triage to trauma centers, delayed recognition of complications and increased mortality. As a marker of physiologic reserve, frailty is a better prognostic factor than chronologic age. Because elderly patients are less able to tolerate injury or subsequent complications, clinicians should approach these patients with a high degree of suspicion and a low threshold to transfer to a higher level of care to achieve rescue. Trauma may be a sentinel event leading to loss of function and independence, and this should be reflected in conversations that outline realistic expectations for patients and families.

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Anticoagulation and Trauma

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BACKGROUND

In 1933 Professor Karl-Paul Link of the University of Wisconsin first learned that coumarin, a component of clover hay, was leading to death in cattle from bleeding complications. He created a use for it as a rodenticide and called it warfarin. Warfarin first gained notoriety in 1955 when it was prescribed to President Eisenhower following a myocardial infarction. Physicians began to prescribe warfarin to patients with arrhythmias for stroke prevention, but this was mainly an empiric approach since we were decades away from establishing data on efficacy or safety.

Barritt and Jordan performed the first randomized trial with warfarin in patients with pulmonary emboli and showed improved outcomes in the Lancet in 1960.[1] An ongoing problem was the dosing of anticoagulation since lab testing of prothrombin time (PT) was variable among institutions due to difficulty in obtaining uniform thromboplastin reagents. Additionally, there was also little agreement as to what degree a patient should be anticoagulated. Since this original trial, there have been numerous investigations establishing the benefit of anticoagulation for deep venous thrombosis, pulmonary emboli, stroke prevention in patients with atrial fibrillation, and other cardiovascular disease processes.

Currently the use of anticoagulation agents is rapidly increasing as atrial arrhythmias, valvular diseases and other forms of cardiovascular disease are more prevalent in our growing elderly population. Warfarin is used in approximately 13% of patients over 65 but its use is decreasing as direct or "novel" anticoagulants become more popular.[2] The widespread use of anticoagulants is problematic in trauma since it increases bleeding risk and worsen outcomes in trauma patients, especially those with traumatic brain injury (TBI).[3] In light of Rhode Island's large population of older adults, a cohort which is projected to double within the next two decades, it is pertinent to review the use of these agents and their impact on trauma care. We will discuss indications for anticoagulant use, their impact on trauma, and their reversal in order to make better decisions about their long-term use.

INDICATIONS FOR ANTICOAGULATION USE

In the last 50 years the indications for anticoagulation use has been tailored through large, randomized, multi-institutional trials. In 1994 a pooled analysis of 5 of these trials revealed a stroke rate of 4.5% in untreated control patients with atrial fibrillation and a rate of 1.4% in those treated with warfarin.[4] A subsequent meta-analysis from JAMA in 2002 showed a 45% reduction in CVA and 29% reduction in cardiovascular events when warfarin was used in patients with non-valvular atrial fibrillation. These authors found a significant increase in rates of major bleeding with warfarin, stating that for every 1,000 patients with atrial fibrillation treated with warfarin, 23 ischemic CVAs would be prevented while 9 major bleeding events would occur.[5] It is accepted that anticoagulation is beneficial for prevention of CVA and other thromboembolic events but that there is no regimen that is both effective and limits bleeding risks. Other common indications for anticoagulation include pulmonary embolus, deep vein thrombosis, congestive heart failure, known atrial clot, and mechanical heart valves. There is less controversy about the indications, but discussions remain regarding duration and degree of anticoagulation.

CHADS$_2$ AND CHA$_2$DS$_2$-VASc

The most effective anticoagulation strategy minimizes complications, namely bleeding events and exacerbation of injuries, by optimizing patient selection. Most efforts have focused on identifying thromboembolic risk in patients while not assessing risk of trauma or bleeding. The CHADS$_2$ scoring system utilizes the following risk factors for ischemic CVA: congestive heart failure, hypertension, age greater than 75 years, diabetes, and history of prior CVA or transient ischemic attack (TIA). It was developed using a Medicare registry of over 2,000 patient-years of follow-up and was more accurate that two other prediction models. CVA rate was noted to increase by a factor of 1.5 for each one-point increase in CHADS$_2$ score.[6] In an attempt to refine this model, CHA$_2$DS$_2$-VASc system incorporated additional categories for vascular disease, age stratification, and sex. The American College of Cardiology, American Heart Association, and European Society of Cardiology recommend use of the CHA$_2$DS$_2$-VASc score to guide decision making. If the bleeding risk per year with anticoagulation is approximately 1–1.5% based on earlier literature, patients should only start an agent if their CVA risk is greater than 1–2% which corresponds to a CHA$_2$DS$_2$-VASc score of two or greater.

EXACERBATION OF INJURY WITH ANTICOAGULANTS

With millions of Americans and thousands of Rhode Islanders on anticoagulation, it is important to understand how anticoagulants affect outcome after injury. An early assessment of 212 patients with subdural hematomas found that 46 of these patients were on anticoagulation; thus anticoagulation appeared to be a risk factor for ICH.[7] Later, patients that suffered intraparenchymal brain hemorrhage and subdural hematoma were found to be at higher risk of death compared to patients who suffered similar injuries while not on anticoagulation.[8]

There remains a deficit in data regarding hemorrhagic complications and exacerbation of traumatic injury. The gap in data was filled in significantly in the 2000s with several retrospective reviews. A 5-year review of 3,000 injured patients showed those with INR>1.5 had a relative mortality risk of 3.3 compared to those with INR<1.5.[9] A meta-analysis suggests risk of death from blunt head trauma was doubled in patients on pre-injury warfarin in the 11 pooled studies.[10] Additionally, in our clinical experience at the Rhode Island Trauma Center (RITC), there are large numbers of advanced-age patients that present with low-energy mechanisms (e.g. falls from standing, minor contusions, etc.) that suffer significant morbidity from subcutaneous hematomas due to anticoagulation. These cases and types of injury are not well described in the literature despite requiring hospital admission, transfusions and occasionally operative intervention. It is likely that inclusion of these types of injuries in prior studies would have negated some of the benefits of anticoagulation.

AS THROMBOEMBOLIC RISK RISES SO DOES RISK OF FALLS, TRAUMA EXACERBATION

Those patients at highest risk of thromboembolic events are also at greatest risk of suffering falls and worse outcomes after trauma. This is also illustrated by reviewing components of the CHA_2DS_2-VASc score; patients of increased age with comorbidities such as CHF, diabetes, and vascular disease are more likely to benefit from thromboembolic prevention while also being more likely to suffer trauma such as falls. Also, these individuals have decreased physiologic reserve and are faced with a more difficult recovery after injury. Strategies of aiming for an INR goal of 1.5–2 have been attempted but there is not enough evidence to recommend the practice.[11]

NOVEL, DIRECT ANTICOAGULANTS

Direct thrombin and factor Xa inhibitors, also known as direct oral anticoagulants (DOACs), are increasingly popular since no monitoring is necessary, unlike with vitamin K antagonists. DOACs are unaffected by dietary changes and have fewer medication interactions. Dabigatran was approved in 2010 for patients with non-valvular atrial fibrillation and the landmark RE-LY trial found similar efficacy with lower bleeding rates with dabigatran compared to warfarin.[12] Other DOACs include melagatran, a thrombin inhibitor, and rivaroxaban and apixaban, both Factor Xa inhibitors. In a 5-year review that compared apixaban, rivaroxaban, and dabigatran to warfarin, patients on apixaban were found to have the lowest rates of CVA or systemic embolism. Apixaban and dabigatran were associated with lower bleeding risk than warfarin.[13] In the early stages of DOAC use, trauma surgeons and emergency medicine providers were concerned about the lack of reversal agents and it was assumed that trauma morbidity and mortality would be increased compared to warfarin. However, a recent retrospective review of injured elderly patients did not show differences in mortality, blood transfusion requirements, and length-of-stay when DOACs were compared to warfarin.[14] Conversely, patients with major blunt trauma, defined as injury severity scores above 15, were shown to have lower rates of mortality and need for transfusion when on pre-injury DOACs versus warfarin.

Head-injured patients are the most vulnerable to bleeding exacerbation from anticoagulation use. DOAC use has been associated with significantly lower mortality, and decreased rates of operative management and discharge to a skilled nursing facility compared to warfarin in cases of blunt TBI.[15] In patients over 65 years of age with ICH from low level falls, there was no difference in mortality, but lower rates of transfusion and shorter ICU length-of-stay with DOACs have been noted compared to warfarin.[16] The reason for these findings may be that, unlike with warfarin, patients do not become "supra-therapeutic" on DOACs due to their fixed dosing.

REVERSAL OF ANTICOAGULATION AFTER INJURY

For reversal of warfarin, most trauma centers including ours, have shifted from using fresh frozen plasma (FFP) and vitamin K to prothrombin complex concentrates (PCC) and vitamin K. PCCs are stored in a freeze-dried powder form and can be rapidly reconstituted without delay, unlike FFP, which requires thawing. The concentration of vitamin K dependent clotting factors of PCCs is much greater than that of FFP. We use 4-factor PCC containing factors II, VII, IX, and X preferentially instead of 3-factor versions of PCC. In the literature, the proportion of patients with INR less than 1.2, within 3 hours of administration, was shown to be 67% versus 9% in ICH patients that received PCC versus FFP. In fact, a 2016 randomized trial was suspended due to safety concerns regarding the low rate of patients' INRs correction with FFP.[17] Timeliness of INR correction is especially critical in closed non-expansile spaces such as the skull or vertebral column where the goal is to rapidly avoid hematoma expansion.

Patients on DOACs that present with injuries are more complicated. Dabigatran was on the market for more than 5 years before its reversal agent idarucizumab became available. Idarucizumab is a monoclonal antibody fragment that binds strongly to dabigatran and was approved in 2015. Prior to this, urgent hemodialysis was the only way to reduce drug levels of dabigatran, but this was cumbersome. Idarucizumab is used to reverse dabigatran similarly to how PCCs are used to reverse warfarin. In a trial of patients suffering serious bleeding consequences while taking dabigatran, idarucizumab was shown to normalize clotting times in minutes, with side effects and cost comparable to a dose of PCC.[18]

In patients with normal renal function, Factor Xa inhibitors apixaban and rivaroxaban, have a shorter half-life of 7–9 hours in comparison to dabigatran, whose half-life extends 14–17 hours. Recently, a reversal agent for these drugs, andexanet alfa, became available. While this agent fully reverses the action of apixaban and rivaroxaban in minutes, at present its therapeutic profile is narrow. Andexanet competitively inhibits the factor Xa at its active site, however there is limited evidence in the literature of the efficacy of this agent and there is no head-to-head data comparing it to PCC, while thrombotic events appear to be more frequent than with PCC.[19] Furthermore, andexanet is difficult to reconstitute and there is a delay of a half an hour or more in preparing it, and its cost is prohibitive. Until additional evidence is available, and changes are made to the formulation of this agent, its benefits as a reversal agent are more theoretical than real. Many trauma centers, including ours, have opted to use an "end-around" strategy by giving a higher dose of PCC to overcome anticoagulant effects of apixaban and rivaroxaban.

GOALS, FUTURE DIRECTIONS TO IMPROVE SAFETY, OUTCOMES

Until recently there has been no objective way to assess the risk of major bleeding in patients on anticoagulation agents. To overcome this obstacle, HAS-BLED, a scoring system that assesses the 1-year risk of major bleeding events in patients on anticoagulation for atrial fibrillation, was developed. The HAS-BLED tool incorporates comorbidities including hypertension, renal/liver dysfunction, prior CVA, history of bleeding, labile INR, age, and use of drugs or alcohol, to produce a score of 0-9 with some components overlapping with CHA_2DS_2-VASc. Scores of greater than 2 are considered higher risk. Increasing HAS-BLED scores have been associated with stepwise increases in rates of major bleeding events in a cohort of more than 7,000 patients.[20] We routinely tabulate HAS-BLED scores on patients admitted to the RITC to guide our conversations with primary prescribers about long-term anticoagulation plans.

While HAS-BLED and CHA_2DS_2-VASc provide important data points, our trauma group routinely discusses the indications and safety of anticoagulation in individual geriatric patients with the primary prescriber following admission. In 2015 we commenced a protocol, with support from an institutional grant, to study the results of our conversations with primary prescribers whether to restart anticoagulation at discharge, stop it indefinitely, or until follow-up evaluation with the prescriber. The most common result was for anticoagulation to be held until follow-up evaluation with the prescriber. Patients with disposition to home versus a facility and those under 75 years of age were more likely to resume anticoagulation at discharge while those that suffered a fall mechanism were less likely to resume anticoagulation. After the study period ended, this protocol was instituted as standard of care at our center. While it is hard to quantitate, we think this practice has improved patient safety and primary provider satisfaction. Future research will focus on frailty, a condition that is a potent indicator of susceptibility to complications and adverse events, rather than chronologic age and portends poor outcomes of many medical interventions.

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Practice Makes Perfect: The Evolution of Blunt Chest Trauma

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Thoracic trauma is the second most common injury in the United States and is associated with significant morbidity and mortality.[1,2] Fractured ribs are the most common thoracic injury and can occur due to a variety of mechanisms ranging from motor vehicle collisions to falls from standing, particularly in the elderly. Historically, the clinical significance of rib fractures was underestimated by clinicians. Over the last few decades the dangers of rib fractures have become more widely known and treatment has improved.[2,3,4] The Rhode Island Trauma Center (RITC) at Rhode Island Hospital is the busiest level 1 trauma center in New England and admits nearly 4,000 injured patients each year, 25% of whom have sustained fractured ribs. RITC employs an evidence-based, multi-modal rib fracture protocol that is continually updated and has achieved excellent outcomes.[1]

A review of the National Trauma Data Bank for patients with rib fractures revealed complications in 13% of patients and a mortality rate of 10%.[2] Complications from rib fractures include atelectasis, hemo- and pneumo-thoraces, pneumonia, Acute Respiratory Distress Syndrome, pulmonary embolus, and empyema.[2] Additionally, as the number of rib fractures increases, the risk of significant complications also increases.[2,3] Much of the morbidity of rib fractures is commonly due to poor pain control leading to ineffective pulmonary toilet resulting in atelectasis, pneumonia, and respiratory failure. Multiple institutions have shown improved outcomes when treatment protocols are implemented for patients with rib fractures.[5,6] Elderly patients are a particularly vulnerable population when it comes to complications related to rib fractures.[3,4] In fact, one study has shown that the increase in morbidity begins as early as the age of forty-five.[4]

Rib fractures results in poor pulmonary function due to a combination of both severe pain and pulmonary toilet as well as altered pulmonary mechanics. In most bone fractures, stabilization to minimize movement results in dramatic improvement in pain and facilitates faster healing and recovery. However, in rib fracture cases, the fractures are difficult to stabilize, resulting in pain from rib movement with each breath. Coughing and sneezing can induce incapacitating pain. Due to the pain, patients are predisposed to the complications previously mentioned. In addition to the pain-related complications, the effects of rib fractures on the mechanical function of the chest can contribute to morbidity. Flail chest occurs as the result of multiple adjacent ribs fractured in two or more places. The flail segment behaves as an independent island of chest wall and moves paradoxically in relation to the rest of the chest wall. Clinically the flail segment appears to collapse inward with respiration as the rest of the chest expands outward. This can result in a rapidly progressive respiratory failure. Consequently, management of rib fractures and flail chest focuses on controlling pain and improving pulmonary mechanics, but there is a high incidence of respiratory failure requiring mechanical ventilation. This type of respiratory failure is not readily reversible, and many elderly patients, and their families opt for comfort measures rather than intubation, tracheostomy and long-term custodial care.

RIB FRACTURE PROTOCOL

The rib fracture protocol at RITC employs a multi-disciplinary approach to managing patients with rib fractures. The core tenets of the protocol focus on pain control, pulmonary toilet, and restoring normal pulmonary mechanics, with fracture stabilization a newer addition to our treatment regimen. The protocol depends on all members of the treatment team, including, nursing, respiratory therapy, physical and occupational therapy, and physicians as well as the patient their family and friends.

PAIN MANAGEMENT

Adequate pain control has been recognized as a vital component of rib fracture management for decades, but recently newer methods of pain control have emerged to improve outcomes in patients with rib fractures. The goal of therapy is to achieve the greatest degree of pain control with the least risk of side effects. Combination therapies utilizing several different agents are preferred in order to minimize the adverse effects of large doses of narcotics.

All trauma patients with rib fractures are initially treated with acetaminophen and ibuprofen unless contraindicated. These medications provide adequate relief for some patients and have a relatively low-risk side-effect profile. Ideally, these agents are dosed on an alternating regimen in order to provide better continuous relief. Administration of ketorolac has been shown to decrease ventilator days and frequency of pneumonia and recent evidence indicates that the previously used doses may be cut in half without a degradation in their pain reliving properties. Unfortunately, many elderly patients have diminished glomerular filtration rates as a normal part of aging, despite a "normal" serum creatinine level, thus NSAIDs are frequently contra-indicated in this population. Topical lidocaine patches have been advocated for rib fracture pain, but data regarding these patches is equivocal.[8,9] In our practice, we have seen benefit in some patients with a low side-effect profile when the 5% strength patches are used, but this benefit is often lost at lower concentrations.

Typically, patients admitted with rib fractures need more potent pain medications added to their regimen, and opioids play an important role in controlling this pain. Narcotic pain medicines provide good pain control in many patients but carry the risk for complications due to respiratory depression or dependency. At RITC we carefully create a treatment plan for patients requiring narcotics to minimize prolonged narcotic use and we have been able to manage most patients without too much difficulty.

Regional anesthetics and catheter-based pain control has been used for decades in many areas of medicine, especially obstetrical care, but have been under-utilized in patients with rib fractures. Epidural catheters have been shown to improve outcomes in multiple studies[2,3,10] and catheter-based therapy has been recommended by a joint practice management guideline from the Eastern Association for the Surgery of Trauma and the Trauma Anesthesiology Society.[11] Despite evidence demonstrating improved outcomes with epidural catheters, many providers are reluctant to place catheters due to perceived risks or contraindications in injured patients (spinal fractures, coagulopathy).

For patients with contraindications to epidural catheters, newer, less invasive catheter-based technologies have proven effective and safe for improving rib fracture pain. We have begun using erector spinae blocks (ESB) placed by the anesthesia team with excellent success controlling pain. The catheter for an ESB is placed outside the vertebral column, which decreases the risk of nerve injury and epidural hematomas. Additionally, these catheters can be placed in patients with spinal fractures and/or in patients with coagulopathy or who have recently taken anticoagulants. Multiple studies have now shown improved outcomes in patients with rib fractures following placement of erector spinae blocks.[12,13]

PULMONARY HYGIENE

In addition to good pain control, pulmonary hygiene is paramount in avoiding complications due to rib fractures. All patients admitted to the RITC with rib fractures are assessed with the rib fracture protocol and treated with an aggressive regimen of incentive spirometry and early mobilization when possible. Patients are tested on their maximal inspired volume upon admission and followed throughout their hospital course to assess for worsening pulmonary function. An initial low incentive spirometry volume may predict eventual respiratory compromise and need for positive pressure ventilation.[15] Brown et al. demonstrated the feasibility and utility of a nurse-driven protocol to use Incentive spirometry to predict impending respiratory compromise.[14] The rib fracture protocol also facilitates early mobilization by nursing through multidisciplinary rounds and frequent communication between nursing and the trauma team. Any patients with mobility concerns are then referred early for a physical therapy evaluation.

RIB STABILIZATION

Although fixation of rib fractures is not a new therapy, there has been a renewed interest in operatively stabilizing ribs over the last decade as new technology and risk stratified data has shown improved outcomes in some patients following rib open reduction internal fixation (ORIF). The stabilization of the rib fractures is believed to reduce the pain associated with movement of the fractured ribs. Multiple studies have shown improved pulmonary function tests, shortened hospital and ICU lengths of stays, and decreased ventilator days with surgical fixation of rib fractures.[16] Majercik et al demonstrated high patient satisfaction with surgical rib stabilization and 90% of patients were able to return to the same work as prior to their injuries.[17]

We use a rib scoring system to predict patients at risk for morbidity and consider rib fixation in high-risk patients. Patients with significant blunt thoracic trauma have 3D reconstruction of the rib cage performed utilizing the data obtained during their initial CT scan to facilitate characterization of the rib fractures. Patients with any of the following are considered for surgical rib stabilization: flail chest, 30% loss of thoracic volume, and aligned fractures in 3 or more consecutive ribs or severe displacement of rib fractures. Additionally, patients with symptomatic fractures refractory to multi-modal pain control efforts or chronic pain from poorly healed fractures or non-unions may be considered for rib ORIF.

Patients undergoing rib stabilization generally receive an epidural prior to surgery. We then proceed with a muscle-sparing chest wall incision over the ribs to be plated. Through this incision the fractured ribs are exposed and realigned. In the case of volume loss, the internally displaced ribs are elevated to restore the chest wall volume. Titanium plates are then used to span the fracture and fixate the fractured rib in the proper anatomic position. A video-assisted thorascopic evaluation of the pleural space is performed at the completion of the case to evacuate any hemothorax and facilitate proper chest tube placement.

In our series of patients, most people have had significant improvement in their pain scores and pulmonary function early after surgery with a very low complication rate. Patients are out of bed on postoperative day one and the chest tube is usually removed within two days.

RIB FRACTURES IN THE GERIATRIC POPULATION

Rib fractures in older patients carry a significantly worse outcome than in younger patients. Patients aged 65 years and older experience significantly higher rates of pneumonia and have higher rates of mortality especially when their fractures are refractory to multi-modal pain control efforts.[3,17] A meta-analysis revealed an odds ratio for mortality of 1.98 for patients 65 years and older.[18] There are likely multiple reasons for this increase in mortality, including, comorbid medical conditions, reduced physiologic reserve, and a narrow therapeutic window for treatments for rib fractures.

In order to improve outcomes in our geriatric patients, the RITC initiated a geriatric rib fracture protocol in 2009. Patients aged 65 and older with 2 or more rib fractures were admitted to the trauma ICU where our nurses focus on aggressive pain control, assessment of pulmonary function via incentive spirometry monitoring, physical therapy and optimizing nutrition. The inspiratory volume achieved on the incentive spirometer was followed and if the patient is not able to achieve 10-15 ml/kg on the spirometer or has an inadequate cough, prompt anesthesia consultation is obtained for consideration of an epidural or ESB. Patient outcomes were evaluated before and after the introduction of the protocol. The patients were similar in age and injury severity before and after the protocol. After initiation of the protocol, the rib fracture patients were more likely to be admitted to the ICU (64.4% vs 24.8%, p<0.01). Patients admitted after creation of the protocol had a shorter ICU length of stay (5.5 vs 8 days), fewer patients required mechanical ventilation (5.5 vs 8 days), and the mortality was significantly lower in the protocol group (9% vs 24%; p=0.01).

CONCLUSION

Thoracic trauma and rib fractures are common injuries that can result in significant morbidity and mortality. The Rhode Island Trauma Center cares for hundreds of patients each year with rib fractures. Through a constantly evolving protocol of multi-modal pain control, intensive nursing care, and operative rib stabilization, we have been able to restore health and function to many Rhode Island residents.

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Advances in the Management of Bleeding Trauma Patients

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DAMAGE CONTROL RESUSCITATION (DCR)

Management of traumatic hemorrhage has progressed over the past century. With better understanding of the pathophysiology of hemorrhage and adverse effects of previous practices, resuscitation has shifted to replace lost blood with blood components instead of crystalloids. The resuscitation of injured and bleeding patients is complex and requires a "multi-modal" strategy, now termed damage control resuscitation (DCR).[1]

Damage control resuscitation has three pillars: early surgical control of bleeding, permissive hypotension, and blood product transfusions while avoiding crystalloids. Identifying patients at risk of severe hemorrhage who would benefit from DCR is crucial. Early initiation of these practices in prehospital settings could prevent or minimize physiologic complications such as organ failure and mortality, while avoiding excessive use of blood products.

Permissive hypotension

Permissive hypotension is a management strategy in which resuscitation is withheld in patients until surgical control of bleeding is obtained. In order to prevent disruption of local hemostatsis at the site of injury, providers administer blood or fluids to maintain a systolic blood pressure of about 80 mmHg or to a level that results in an adequate mental status and tissue perfusion.[2] Additionally, permissive hypotension may decrease post-operative coagulopathy and lessen nonsurgical bleeding. While several studies have been unable to definitively demonstrate a survival benefit, trends do suggest decreased mortality in both the first 24 hours of care, as well as in-hospital mortality.[3,4]

Blood Resuscitation

Current guidelines indicate that bleeding patients should be resuscitated with blood products instead of crystalloid fluids. Traditional administration of large amount of crystalloid increase the risk of outcomes, such as abdominal compartment syndrome, acute respiratory distress syndrome, dilutional coagulopathy and hyperchloremic metabolic acidosis.[5] Simply put, if a patient loses blood, it should be replaced with blood.

Advantages of blood components resuscitation come from their inherent properties – oxygen carrying capacity, presence of coagulation factors and platelets, and avoidance of some of the negative sequelae of saline containing fluid. Using whole blood for resuscitation appears to be the logical choice since it contains the ideal amounts of hemoglobin, platelets and clotting factors. Military protocols have made this a practical element of damage control resuscitation in combat and military personnel are often thought of as "walking blood banks". However, due to storage and other logistical limitations, whole blood cannot be widely used as a resuscitative fluid. On the contrary, in civilian centers, blood is separated into its components – packed red blood cells (PRBC), plasma, and platelets – to prolong storage duration and availability.

The PROPPR and PROMIT trials examined the ideal ratios of blood components during massive transfusion.[6,7] A balanced resuscitation that is as close to 1:1:1 of plasma: platelet: PRBC appears to be the most beneficial. This represents a significant departure from past practices where blood components were ordered in response to lab value-detected deficiencies and plasma was not transfused until after 4 or more units of blood were administered. Ensuring early balanced blood resuscitation also appears to improve survival in hemorrhaging trauma patients compared to the common practice of transfusing PRBC first and then catching up with other components later in the resuscitation.[8]

The benefit of adding plasma and platelets (*plus fibrinogen*) early in resuscitation is due to their role in halting and correcting trauma-induced coagulopathy. The COMBAT and PAMPer trials evaluated whether administering plasma in prehospital settings en route to trauma centers offered any advantage.[9,10] These studies were designed to simulate rapid and slow transport to a trauma center, respectively. Prehospital plasma administration appears to have the advantage in settings with longer transport times, but not in cases where there is rapid transport to a definitive care setting. Additionally, there are logistical issues to consider. Fresh frozen plasma requires cold storage and then thawing prior to administration which renders it extremely difficult to use in the prehospital setting. Pre-thawed plasma will resolve the storage and thawing limitations; however, it has a short shelf life (<5 days), which leads to increased waste in areas with infrequent rates of use. Never-frozen plasma has a longer lifetime and is possibly the best option in the pre-hospital settings. Freeze-dried plasma has been tested and appears to have similar coagulation parameters with the advantage of easy storage and transport.[11,12] Shelf life is about 2 years and reconstitution only requires mixture with distilled water prior to administration, but this product is not yet approved by the Food and Drug Administration.

Hemorrhage Control

Early management of hemorrhage depends on rapid control of the bleeding site. Traumatic hemorrhage can be divided into two categories – compressible and non-compressible. For compressible hemorrhage, pre-hospital interventions have proven to be extremely beneficial. The easiest and fastest method of controlling compressible hemorrhage is direct pressure to the bleeding site. Tourniquets applied by pre-hospital providers, police officers, or bystanders can reduce blood loss from injured extremities significantly, improving survival rates.[13,14] Hemostatic dressings were developed to simultaneously provide direct pressure as well as initiate thrombotic reaction resulting in cessation of bleeding

Non-compressible hemorrhage occurs in a cavity where direct pressure or tourniquet use is not possible, such as the thoracic cavity, the abdomen, or the pelvis. Traditionally, once a non-compressible hemorrhage is identified, the patient is transported immediately to the operating room or the interventional radiology suite for control of the source of hemorrhage. Occasionally, in patients with impending traumatic cardiac arrest or those who lose vital signs due to hemorrhage, an emergency department thoracotomy (EDT) is performed to provide manual control of the source of hemorrhage in the chest or clamp the descending aorta in order to halt bleeding in the abdomen or the pelvis. Recently, a minimally invasive approach has gained acceptance in the trauma community to provide early and temporary control of bleeding in the abdomen or the pelvis. The resuscitative endovascular occlusion of the aorta (REBOA) technology borrows from skills commonly used in vascular surgery to deploy a balloon in the descending aorta, like aortic clamping performed in EDT. Advances in this technology have shortened time to access and correct placement of the balloon in the aorta. The aorta is divided into three zones of balloon placement. Zone 1 is in the thoracic descending aorta above the celiac artery and equates with the xiphoid process. The balloon is deployed in zone 1 when intra-abdominal hemorrhage is suspected. Zone 3 lies between the renal arteries and the bifurcation if the aorta. The provider inflates the balloon in zone 3 only if pelvic bleeding is suspected due to presence of pelvic fractures while abdominal sources of bleeding are ruled out. Zone 2 extends from the celiac artery to the renal arteries. The balloon should not be inflated in zone 2 under any circumstances, to prevent ischemic insult to the kidneys and viscera.[15]

Several centers have implemented REBOA in their damage control resuscitation protocols and have begun reporting their results. Early data supports its use; however, these studies have been critiqued due to lack of an appropriate comparison group.[16] Joseph et al compared REBOA to a control group using propensity score matching and placement of REBOA resulted in higher mortality and morbidity.[17] These results should not be interpreted as lack of evidence of benefit. Instead, they should lead to further assessment to identify the injured and bleeding population that could benefit the most from this approach. Pre-hospital application should not be initiated or discussed until more solid data on REBOA's safety and efficacy has been established.

Experimental Approach – ResQFoam

For non-compressible hemorrhage, presently there is no quick option for applying direct pressure at the bleeding site. Immediate surgical control is the only intervention most of the time, with REBOA being an occasional temporary choice *en route* to the OR. Recently, an experimental technology for abdominal hemorrhage was approved for a clinical trial (*Clinicaltirals.gov: NCT02880163*). This product uses an expandable polyurethane foam that is injected into the peritoneal cavity to create a tamponade effect in the abdomen to stop or slow bleeding as an adjunct to other damage control resuscitation components.[18,19] Foam is administered into the abdomen within 30 minutes of arrival to the emergency department with definitive surgical intervention to be carried out within 3 hours from foam deployment. Fortunately, this foam does not adhere to vitals structures or organs which facilitates its prompt removal once the peritoneal cavity is opened.

Correcting Coagulopathy

Bleeding in injured patients can be complicated by the development of trauma-coagulopathy. Resuscitation with blood components, plasma, platelets, and fibrinogen, replace lost and consumed clotting factors. Hemostasis and clotting are tightly coupled to fibrinolysis and dissolution of clots, lest the entire circulatory system would thrombose once clotting was initiated. Injured patients are at risk for excessive fibrinolysis which promotes bleeding and the development of the lethal triad. Tranexamic acid (TXA) is a lysine analogue that results in reversal of thrombolysis. The widespread pre-hospital use of TXA is based on the CRASH 2 trial, which showed a mortality benefit in patients who were suspected of hemorrhage and received TXA.[20] However, there were several study design issues and the treatment effect size was small, reducing mortality due to severe hemorrhage from 5.6% to 4.8%. This meant that 125 patients needed to be treated with tranexamic acid to prevent one death. The MATTERs study, a retrospective study of TXA in military settings, showed a mortality benefit due to administration of TXA.[21] As a result of these two studies, tranexamic acid has become widely used in massive transfusion protocols nationally and internationally. Pre-hospital use has also increased, although there are not enough robust studies to support its prehospital use. The Department of Health in

Rhode Island recommends administering TXA for injured patients with hypotension, tachycardia, or if the prehospital provider determines that the patient is at *risk* of hemorrhage. When we examined local TXA practices we identified a high rate of administration without clear indication when given by EMS. We believe that TXA should be administered cautiously, ideally in patients with hemorrhage and evidence of fibrinolysis. Data from University of Pittsburg showed a 3-fold increase in the rate of VTE events, thus further studies are needed to establish appropriate criteria to guide pre-hospital providers to administer such an important medication. [22]

Traditionally, evaluation of trauma coagulopathy has relied on tests such as PT, PTT, and INR. The results of these tests are delayed and do not reflect the actual coagulation status of an injured, hypothermic and actively bleeding patient. Additionally, these standard clinical tests are normalized and run at 37°C, while nearly half of all bleeding trauma patients arrive at the hospital hypothermic. Fortunately, there is a technology that provides an assessment of the entire coagulation and thrombolysis status of the patient. This technology, thromboelastogram (TEG), assesses the time to bleeding, the strength of the formed clot, as well as the dissolution of the clot or thrombolysis. Advances in this technology have allowed trauma surgeons to obtain timely and early assessments of the coagulopathy in trauma patients. Therefore, a tailored resuscitation with blood products and choice of pharmacological resources can be given to an injured trauma patient resulting in less products utilization and rapid correction of coagulopathy.

STOP THE BLEED CAMPAIGN

Resuscitation and control of traumatic hemorrhage has evolved. Management commences with arrival of prehospital providers where control of compressible hemorrhage is performed, and blood product resuscitation is initiated. Rapid transport to a trauma center within a mature trauma system network ensures timely expert surgical management for these patients – continued resuscitation, correction of coagulopathy and surgical control. However, in cases where prehospital care is delayed due to mass casualty, an active shooter, or logistical factors, some interventions that could be provided by bystanders may prove to be lifesaving. The Stop The Bleed initiative by the American College of Surgeons' Committee on Trauma and the Hartford Consensus aims to educate lay people on the proper use of tourniquets and hemostatic dressings applications, among other first aid measures, prior to arrival of EMS providers. [23] In neighboring Connecticut (CT), kits containing essential tools for early hemorrhage control (pressure bandages, hemostatic dressings, tourniquets, and personal protective gloves) are placed alongside every automatic external defibrillators in public places. This strategy was mandated by legislation in CT aiming to reduce preventable deaths due to compressible hemorrhage. Bleeding control or "B-con" courses are educational seminars that are routinely provided to large groups such as schools, civic groups, sporting events, etc. The short classes consist of a formal presentation and hands-on practice of bleeding control. In two years since its official launch in February 2017, more than 40,000 classes have been conducted in 77 countries with over 600,000 attendees trained in bystander hemorrhage control methods. Participation, especially when hands-on training is provided, improved laypersons' willingness to use a tourniquet in an emergency.[24] Community education to raise awareness regarding the importance of participation in early bleeding control and engaging in B-Con courses continues to be an important public health matter.[25]

CONCLUSION

Improved understanding of the pathophysiology of hemorrhage, coagulopathy, and resuscitation, along with technical advances and innovations, have improved outcomes of bleeding trauma patients. but there continues to be a need for early hemorrhage control. Involving bystanders appears to be a promising approach toward improving outcomes. Ongoing research and support by academic and government institutions is a crucial factor in combating mortality from traumatic hemorrhage – a serious public health problem.

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Predicting Outcomes in Acute Traumatic Brain Injury (TBI)

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"No head injury is so serious that it should be despaired of nor so trivial that it can be ignored." — Hippocrates

INTRODUCTION

Acute traumatic brain injury (TBI) is a heterogenous disease ranging from mild concussion to contusions, extra-axial hematomas and traumatic subarachnoid hemorrhage to diffuse axonal injury. It is a leading cause of death and disability in the United States. In 2013, there were 2.5 million emergency department visits and more than 55,000 deaths due to TBI, and TBI accounts for approximately 30% of all injury-related deaths.[1] Both injuries and hospitalization rates have increased markedly between 2007 and 2013, and while death due to motor vehicle crashes have decreased, age-adjusted rates of TBI-related ED visits have increased between 2007 and 2013.[1] The aggregate leading cause of death among TBI patients is now due to intentional self harm but motor vehicle collisions, sports, and combat-related injuries continue to afflict children and adolescents/young adults (age 0–4, and 15–24 years).[1] Older adults have also suffered from an increase in TBI-related hospitalizations and deaths, primarily due to falls.[1] These numbers are likely underestimates of the prevalence of TBI, because they do not include persons with TBI sequelae who were treated and released from emergency departments, those who sought care in other healthcare settings, and those who did not seek treatment.[2,3]

Data from Rhode Island mirrors the national trend. In 2018, 134 children suffered moderate to severe TBI and 6 died. At Rhode Island Hospital, more than 800 adult patients with traumatic brain injury are hospitalized annually, and in 2018, at Rhode Island Hospital, more than 500 adult patients with TBI required long-term care and more than 100 patients died in the acute setting.

Despite significant improvements in the care of the head-injured trauma patient over the last decade, challenges remain in both the treatment and assessment of prognosis of patients who have suffered traumatic brain injuries. The higher incidence of TBI coupled with a lower death rate suggests that there is a growing population of individuals living with a disability related to their TBI.[4] Improved understanding of TBI can help guide resource allocation as well as patient and family discussions regarding goals of care in the more acute setting. Here we aim to describe some of the scoring systems and predictive models we use to best understand outcomes for patients with traumatic brain injury.

SCORING SYSTEMS

The Glasgow Coma Scale (GCS) was first described in 1974 to communicate accurately about patients with impaired consciousness. The GCS is used in more than 80 countries and, 45 years later, the original report is the most quoted paper in the neurosurgical literature.[5]

A key element of the GCS is the motor score (GCS_M). The motor score consists of 6 categories and has been validated to be specific in predicting patients with TBI.[6] With this, the Simplified Motor Score (SMS) was developed combining the components of the GCS-M and simplifying them into three categories: (1) follows commands, (2) localizes to pain and (3) withdrawals to pain or worse. Two points are given for following commands, one point for localization of pain and no points for withdrawing to pain or worse. Lower scores suggest worse head injury. [7] In 2018, Buitendag et al compared the GCS-M to the SMS and found that there was a decline in survival rate for GCS-M-<4 on admission, and was more pronounced when the score was <3. When plotted against mortality, both the GCS-M and the SMS were accurate, sensitive and specific, suggesting that these more simplified scales can accurately predict outcomes in patients with TBI when the entirety of the GCS model is difficult to assess.[8]

The Glasgow Outcome Scale (GOS), also developed by Jennett in 1974, predicts how patients with TBI recover. It consists of five categories: Death, Persistent Vegetative State, Severe, Moderate, and Low Disability.[9] This scale was refined in 1981 as the Glasgow Outcome Scale Extended (GOSE).[10] Additional categories were added to the GOSE to better describe patients' disabilities. The GOSE is also meant to be reassessed at 3, 6 and 12 months with a structured interview consisting of questions regarding the patient's disabilities. All of these scales (GCS, GOS and GOSE) have been used clinically and in research to help predict which patients will have better global outcomes from traumatic brain injury; however, the timing, utilization and application of these scales has been inconsistent.[11]

More recently, another scoring system is in use to predict the Full Outline of UnResponsiveness (FOUR). The FOUR Score is a neurological assessment score, similar to the Glasgow Coma Score, that adds additional emphasis on brainstem reflexes and respiratory pattern.[12] Alhough a newer scoring system, it is validated and has proven to be a useful measure in predicting mortality and functional recovery. A 2018 systematic review showed that FOUR score was a useful outcome predictor with good inter-rater reliability among physicians and nurses.[13] When compared to GCS, it appeared to perform similarly in predicting mortality.[14]

Radiologic imaging scales, including the Marshall scale and the Rotterdam scale, also contribute to prognostic value as they can predict the risk for increased intracranial pressure and outcome in adults. While each of these scales can predict early death, each has limitations and does not provide accurate prognostic value for patients without severe injury.[15]

Other datasets have contributed to prognosis for severely injured patients. The CRASH trial (Corticosteroid Randomization after Significant Head injury) did not show any improvement in outcome in those patients who received steroids, but the database created was helpful in generating a prognostic calculator. This calculator (http://www.crash.lshtm.ac.uk/Risk%20calculator/index.html) can help physicians determine 14-day mortality as well as death and severe disability at 6 months in patients with TBI.[16] Similar to the database generated by the CRASH trial, in 2007, the International Mission of Prognosis and Clinical Trial-TBI (IMPACT-TBI) examined patients with traumatic brain injury over 3 decades. IMPACT investigators have analyzed the existing database to generate a prognostic score to predict 6-month outcome of patients who suffered moderate to severe TBI (GCS ≤ 12), (http://www.tbi-impact.org/?p=impact/calc).[17]

Unfortunately, none of the scoring systems are able to predict with certainty how patients with TBI will do in both the acute and long-term setting. Further complicating the utility of these scores is the clinician's ability to apply them to their individual patients. However, certain patient characteristics can suggest a better or worse outcome. Young patients continue to do better than older patients in terms of functional recovery from TBI. Not surprisingly, patients with more impairments do worse than those with less impairments. Improvement in disabilities occurs early (if at all), and then plateaus.[18] The extent of these improvements is still very heterogeneous and unpredictable, and frequently, patients who initially improve will eventually decline in their abilities.[19] Recently, Hammond followed patients 10 years post injury. Patients were evaluated at 1, 2, 5 and 10 years from injury. They demonstrated that improvement occurred throughout the 10-year period and those that recovered earlier improved more. These findings suggest that ongoing directed therapy continues to be important as far as 10 years out.[20] However, Forslund et al also followed patients with moderate to severe TBI over a 10-year period looking at change in GOSE. They found that 37% deteriorated, 7% improved and 56% showed no change in global outcome. Additionally, they sought to better define predictors and found that younger, employed patients with shorter post-trauma amnesia did better, consistent with prior literature.[21] Overall, patients with moderate to severe TBI did not improve.

CONCLUSION

The above validated measuring scales and prognosis calculators help us predict the extent of, and recovery from, TBI. Unfortunately, we are still unable to predict which patients to whom these measures best apply. Large databases generated retrospectively have helped us to get closer to predicting the future. However, the ultimate ability to determine true outcomes after TBI will be found by following these patients prospectively after their injuries, thereby generating a database in this fashion. This prospective database has the potential to improve guidance for physicians, patients and families in determining outcomes of patients with traumatic brain injury.

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