Difficult Decisions in Surgery:
An Evidence-Based Approach

Kenneth Wilson
Selwyn O. Rogers *Editors*

Difficult Decisions in Trauma Surgery

An Evidence-Based Approach

Springer

Difficult Decisions in Surgery: An Evidence-Based Approach

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The complexity of decision making in any kind of surgery is growing exponentially. As new technology is introduced, physicians from nonsurgical specialties offer alternative and competing therapies for what was once the exclusive province of the surgeon. In addition, there is increasing knowledge regarding the efficacy of traditional surgical therapies. How to select among these varied and complex approaches is becoming increasingly difficult. These multi-authored books will contain brief chapters, each of which will be devoted to one or two specific questions or decisions that are difficult or controversial. They are intended as current and timely reference sources for practicing surgeons, surgeons in training, and educators that describe the recommended ideal approach, rather than customary care, in selected clinical situations.

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This book is dedicated to the community advocates living in the Southside of Chicago and their grassroot efforts that re-opened the trauma center at the University of Chicago after a 30-year absence. Their unyielding advocacy for fixing broken physiology locally is paramount in creating this international trauma text edited at The University of Chicago.

Preface

In the expiring seconds of an adrenaline-charged competition, the "last shot" is entrusted to the individual with unwavering poise, unperturbed by the gravity of the situation. The correct decision needs to be made when the count on the shot clock is unfavorable. In a similar manner, trauma surgeons are men and women with the same strength of character committed to taking and making the last shot even when competing against death. In the case of the trauma surgeon, the consequence of not being focused in the moment can have dire consequences if stuck entertaining vacillating thoughts as the team lead. Quick and resolute decision-making wins the game.

The unfortunate advent of war over many centuries has produced innumerable injury patterns requiring swift surgical decision-making for bleeding cessation. War-time surgeons over the last century and into the modern era, under compulsion, have improved trauma care by critically evaluating dilemmas and forcing refinements. Innovations in vascular injury management, patient transport, advancements in antibiotics and field resuscitations, all mastered by intrepid surgeons, have considerably impacted how trauma care is delivered today. Civilian clinical decision-making has also been considerably advanced by the conundrum of complex injury patterns experienced by trauma surgeons. In both military and civilian sectors, the trauma surgeon stands often as the last line of defense between severe disability and dying. The decision-making needs to be continuously challenged as new injury patterns emerge relegating some older trauma dictums to a secondary role. Perhaps some things handled with a scalpel by the more "seasoned" surgeon are now better managed by the interventional radiologist! Conversely, the pendulum swing may also revert to being more adept at an open repair when austere locations and hemodynamics (or a lack thereof) do not allow for the calling in of a crew to open the hybrid suite! The pendulum will not rest. What is required of trauma surgeons is to always consider new ideas, unprejudiced by past successes or failures, accepting that there just might still be a better way when being entrusted with taking the last shot. Trauma surgery is mostly muscle memory and preparation. When precious minutes remain, many things must be considered, but a definitive decision must be made when competing against death.

The decision-making required to win at saving lives is the impetus for surveying authors from around the globe to write this book. Each author was given a specific clinical scenario to discuss, highlighting available data while offering their own expertise toward answering difficult branch points in the evaluation and

resuscitation of the injured patient, whether by operative intervention or with the utilization of trauma adjuncts. We hope that this text will serve as an informative guide aligning evidence-based medicine with the need for flexibility and improvisation when treating the injured patient. Prevailing practices by prominent programs, iconic individuals, and a lack of uniformity in patient presentations with underpowered studies alongside a myriad of other factors make analyses difficult. When the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) was created in the year 2000, the intent was to formulate to what extent one could be confident about the quality and strength of recommendations. We assembled experts on each topic in this book to think hard about discrepancies and asked for them to assign a GRADE to each chapter based upon literature review. In addition, each chapter concludes with *"A personal view of the data"* allowing the authors' personal opinion of the data and the application of the data. The inclusion of this short description makes absolute sense because the unscripted nature of trauma often requires deviation from dogma.

All practice locations are not level I academic trauma centers replete with residents, surgical subspecialists, interventional radiologists, and rapidly replenishing blood banks. Globally more lives are saved with far less away from academic centers. This book was created specifically as a resource for community surgeons that have a stake in saving lives and decreasing the sequelae of injury with far less than many of the institutions represented in this text. Despite the authors' affiliations with exceptional academic centers and many years of personal experience, they were requested to present their evaluations of the literature based upon the GRADE criteria as detailed below:

High	There is a lot of confidence that the true effect lies close to that of the estimated effect.
Moderate	There is moderate confidence in the estimated effect: The true effect is likely to be close to the estimated effect, but there is a possibility that it is substantially different.
Low	There is limited effect in the estimated effect: The true effect might be substantially different from the estimated effect.
Very low	There is very little confidence in the estimated effect: The true effect is likely to be substantially different from the estimated effect.

Each chapter was superbly written by the contributing authors and offers practical guidance in addressing difficult decisions in trauma surgery.

Chicago, IL, USA — Kenneth Wilson
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Acknowledgement

Producing this book was a challenge amid a worldwide pandemic. We want to express our sincerest gratitude to all the authors and co-authors that had every reason to decline our requests and focus solely on being clinicians, community leaders or delving deeper into administrative roles during the challenge of the COVID-19 pandemic. Trauma surgery itself lends to compassion fatigue, burn-out, and stress disorders; however, lockdowns, social distancing, and self-isolation from family, and community health concerns during this crisis only exacerbated the challenges of being a trauma surgeon. Thank you for your perseverance and resilience.

Many thanks to Prakash Jagannathan and the entire Springer team that allowed for deadline extensions during this challenging time in our history.

I am indebted to my wife Nichole and four children, Dakota, Cheyenne, Rebekah, and Gabrielle that allowed me to spend many hours away from home to complete this project. I also want to thank Dr. Rogers and Dr. Ferguson, both of whom entrusted me with their vision of creating the inaugural text of Difficult Decisions in Trauma Surgery.

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Contents

Part I Resuscitation

1 Difficult Decisions in Trauma: Is ABC the Right Mantra? 3
John M. Ruggero and Matthew J. Martin

2 Difficult Decisions in Trauma Surgery: What Is the Clinical Impact of Whole Blood as Compared to Component Therapy in Civilian Trauma? 13
Lane L. Frasier, Andrew J. Benjamin, C. William Schwab, and Jeremy W. Cannon

3 Helicopter Emergency Medical Services in Trauma 25
Robel Beyene and Oscar Guillamondegui

4 Futility of Care in Hemorrhagic Shock: When Prolonging the Massive Transfusion Protocol Is of No Benefit 35
Rafael Tolentino, Timothy J. Holleran, and Laura S. Johnson

5 Is it Time for REBOA to be Considered as an Equivalent to Resuscitative Thoracotomy? 45
Tanya Anand, Samer Asmar, and Bellal Joseph

Part II Wound Management

6 In Patients with Traumatic Extremity Wounds Is Negative Pressure Wound Therapy Superior as Compared to Standard Dressing Changes? 61
Brett M. Tracy, Deepika Koganti, and Christopher J. Dente

7 Enterocutaneous Fistula Management in Trauma 73
Alexa P. Soult and Andrew J. Dennis

Part III Antimicrobial Management

8 Does Prophylactic Antibiotics for Emergent Tube Thoracostomy Decrease Rates of Infection? 85
Andy C. Lee and Maria Lucia L. Madariaga

9 Antibiotics Prophylaxis after Penetrating Colon Injuries 99
Ahmad Zeineddin and Mallory Williams

10 Antibiotic Regimen in Treating Complicated Intra-abdominal Infections 105
Melissa Linskey Dougherty and Scott B. Armen

11 Is Vaccine Prophylaxis Necessary for Patients Undergoing Splenic Embolization? 117
Mary Kate Johnson and Natasha N. Pettit

Part IV Trauma Imaging

12 The Trauma Pan-Scan: Who Benefits from Immediate Whole-Body Imaging? 127
Lea Hoefer and Jennifer Cone

13 Nonselective Arterial Embolization for Pelvic Fractures 139
David Graan and Zsolt J. Balogh

14 Clinical Clearance of the Cervical Spine in the Presence of a Distracting Injury 155
Caleb Van Essen, Edward Hagen, and Brian Williams

15 MRI Clearance for the Cervical Spine 163
Marc de Moya and Amy Elizabeth Murphy

Part V Traumatic Brain Injury

16 ECMO Safety in the Setting of Traumatic Brain Injury 173
Brandon Masi Parker, Jay Menaker, and Deborah M. Stein

17 Can Abdominal Decompression Improve Refractory Intracranial Hypertension? 181
Mira Ghneim and Thomas M. Scalea

18 Is There an Optimal Screening Tool to Best Diagnose and Treat Blunt Cerebrovascular Injury (BCVI)? 189
Paramita Das

Part VI Abdominal Trauma

19 Does Specific Sequencing of Operative Interventions in Thoracoabdominal Trauma Improve Outcomes? 199
W. Ian McKinley and Priya S. Prakash

20 Selective Non-operative Management for Abdominal Gunshot Wounds 207
Lindsey Karavites and Kenji Inaba

21 What Is the Optimal Management of Traumatic Duodenal Injury? 219
Jonathan Kent and Peter Bendix

22 Timing of Ostomy Reversal in Trauma and Acute Care Surgery 227
Ryan P. Dumas and Matthew J. Martin

Part VII Thoracic Trauma

23 Resuscitative Thoracotomy 241
Amy V. Gore, Clay Cothren Burlew, and Ernest E. Moore

24 Extracorporeal Membrane Oxygenation for Patients with Traumatic Injury and Respiratory Failure 251
John W. Stokes, Whitney D. Gannon, Matthew Bacchetta, and Mauer Biscotti III

25 Is There a Gold Standard for Screening Blunt Cardiac Injury? 267
Andrew J. Benjamin and Selwyn O. Rogers

26 Optimal Chest Tube Size for Hemothorax Evacuation 281
Asanthi Ratnasekera and Paula Ferrada

27 Tissue Plasminogen Activator (tPA) for Post-traumatic Retained Hemothorax 287
Fletcher K. J. Evans and David C. Evans

28 Rib Plating in the Acute Trauma Setting 297
James Dahm and Jason Strelzow

29 Does Thoracic Irrigation at the Time of Chest Tube Placement Decrease the Incidence of a Retained Hemothorax? 309
Elliot S. Bishop and Louis R. Pizano

30 The Timing of VATS for a Retained Hemothorax 315
Kaitlin A. Ritter, Jamie Coleman, and Mitchell Cohen

Part VIII Ethics

31 Donation After Cardiac Death in the Emergency Department 325
Lisa M. Kodadek, Allan B. Peetz, and Peter Angelos

32 Resuscitative Thoracotomy for Organ Donation 339
Mark Seamon and Jane Keating

33 Resilience Training for the Trauma Surgeon 349
Ava Ferguson Bryan, Kyra Nicholson, and Tanya L. Zakrison

34 Youth Violence Prevention: Violence Recovery Programs 367
Omar K. Danner, Richard Sola, Caroline Butler, and Klahe Butty

Part IX Peripheral Vascular Trauma

35 Are Temporary Vascular Shunts (TVS) Effective Damage Control Adjuncts for Limb Salvage? 381
David Hampton and Kenneth Wilson

36 Difficult Decisions in Surgery: An Evidence-Based Approach Limb Salvage for the Mangled Extremity 391
Valentin Neuhaus and Hans-Christoph Pape

Part X Pediatric Trauma

37 The Use of FAST in the Pediatric Trauma Setting. 423
Minna C. Wieck, Nikunj K. Chokshi, and Grace Z. Mak

38 Selective Nonoperative Management of Children with Penetrating Abdominal Trauma 431
Juan E. Sola and Henri R. Ford

39 Are Outcomes Equivalent for Injured Children Treated at Pediatric Versus Adult Trauma Centers, and What Are the Implications with Respect to the Design of Optimal Trauma Systems? 441
Mark B. Slidell

Index. 451

Part I

Resuscitation

Difficult Decisions in Trauma: Is ABC the Right Mantra?

1

John M. Ruggero and Matthew J. Martin

Introduction

Current practice in most modern civilian trauma centers follows the Advanced Trauma Life Support (ATLS) prioritized approach to evaluation and intervention focusing on Airway (A) Breathing (B) and Circulation (C) ("the ABCs") in the initial assessment of trauma patients. This has been the mainstay of traumatic resuscitation since ATLS's inception and widespread acceptance throughout the medical community. The evidence supporting the pathway and ordering of priorities in the ABC approach is based on expert consensus with little literature to support its clinical application [1]. In approaching this question, it is critically important to understand the principles and rationale behind the "ABC" mantra, the existing epidemiologic and outcome data that supports or refutes this approach, and the likely impact of any program to alter this ingrained sequence in the initial trauma evaluation and resuscitation process.

The rationale and purpose for the ATLS primary survey is to rapidly identify any immediately life-threatening pathology or injuries, to prioritize these from most important to least important, to begin interventions to address the identified problem,

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and to essentially ignore all other non-emergent injuries or problems until later in the evaluation. Although it seemingly makes sense that without a patent airway a patient will rapidly progress to cardiorespiratory arrest, there is little available data that airway should be prioritized in sequence over circulatory and hemorrhage concerns. From an epidemiologic standpoint the incidence of complete airway loss after trauma is relatively low, particularly among survivors to EMS arrival and/or hospital arrival. In comparison, circulation and bleeding issues are much more prevalent and likely causes of early mortality or morbidity, and thus from a simple likelihood standpoint should arguably be prioritized over airway.

If strictly adhering to the dogma of "A" interventions first, especially in a hemodynamically unstable trauma patient, there is a potential to perpetuate or worsen the physiologic derangements that frequently occur with intubation, specifically rapid sequence intubation (RSI). The vasodilatory effects caused by RSI in addition to the effects of positive pressure ventilation may further compromise a hypovolemic/bleeding patient by putting them at risk for more significant hypotension and decreased cardiac output leading to an overall decrease in perfusion [2–6]. For patients in class 3–4 hemorrhagic shock who are awake and have a patent airway, administration of agents that usually include some combination of paralytic and sedative/analgesia often produce a precipitous drop in perfusing pressure, loss of muscle tone, and blunting of the normal catecholamine response. The end result of this is frequently severe instability or rapid progression to cardiac arrest and the need for cardiopulmonary resuscitation while attempting to "catch up" on the resuscitation.

Based on the experiences during military conflicts of the last two decades we have seen the benefits of an aggressive focus on prioritization of "C" interventions focused on hemorrhage control over the usual "A" interventions. This includes prehospital placement of tourniquets, hemostatic dressings, and the use of blood products for resuscitation of hypotensive severely injured trauma patients. These novel techniques have been adopted by many civilian trauma centers and applied to their population [7]. This benefit has been adapted by the military's Tactical Combat Casualty Care (TCCC) course, which uses the approach of controlling life-threatening hemorrhage first prior to airway interventions. This changes the ABC mnemonic of ATLS to either CCAB (Catastrophic hemorrhage; Circulation; Airway; Breathing) or MARCH (Massive hemorrhage; Airway; Respiration; Circulation; Head/Hypothermia). This doctrine is widely accepted as best practice in the realm of military medicine and has yielded numerous improvements in battlefield medicine [8–10]. This approach has also gained significant acceptance among the civilian trauma community in both the pre-hospital and in-hospital phases of care. Numerous efforts aimed at early hemorrhage control and hemostatic resuscitation have been adopted, such as the American College of Surgeons "Stop the Bleed" course, the increased utilization of pre-hospital blood products, and the currently increasing adoption of whole blood for initial trauma resuscitation at many centers.

Simultaneously, there have been no corresponding initiatives with a focus on increasing the utilization of early airway interventions, and in fact many trauma systems have attempted to decrease or even eliminate the use of pre-hospital intubation in select trauma populations.

In addition to the above-mentioned military and civilian trauma community's focus on circulation first there also has been a significant shift in the medical literature in regard to cardiopulmonary resuscitation of medical patients. Focus has been shifted from acquiring an airway or delivering "rescue breaths" first to prioritizing circulation by initiating continuous chest compressions without pauses for airway interventions. These approaches are now widely taught in the Basic Life Support (BLS) and Advanced Cardiac Life Support (ACLS) courses and highlight how the most high-yield interventions to improve outcomes should focus on restoring adequate circulation and central perfusion rather than waste critical minutes on less effective airway interventions or assessments. This has led to overall better outcomes in this population in a number of large analyses and from a variety of causes of cardiopulmonary arrest [11–14].

Obviously, changing the practice and utilization of a uniform and very well-entrenched algorithm such as the "ABCs" approach to severely injured trauma patients is a major challenge. It is currently being adopted in multiple centers across the globe; however, the long-term clinical advantages should be based on sound scientific evidence instead of expert consensus. In this chapter we discuss the literature on the paradigm shift of adopting an approach based on hemorrhage control first prior to airway interventions.

Search Strategy

Our search strategy was to use PUBMED using the keywords airway, circulation, intubation, hemorrhage control, hypotension, pre-hospital, and ATLS. We focused on the two primary PICO questions as shown in Table 1.1. We included and reviewed manuscripts from 1990 to 2020.

Table 1.1 PICO questions for the issue of airway first versus circulation first approach

P (patients)	I (intervention)	C (comparator)	O (outcomes)
Trauma patients in extremis/ hypotensive (in hospital)	Addressing circulation first CAB	Addressing airway first ABC	Mortality Hypotension Transfusion requirements
Trauma patients in extremis/ hypotensive (pre-hospital)	Addressing circulation first CAB	Addressing airway first ABC	Mortality Hypotension Transfusion requirements

Results

Military Experience

As previously mentioned, the military has systematically adopted a practice of assessing for and controlling life-threatening hemorrhage first prior to addressing airway issues. This change in practice was due to the prominence of hemorrhage as a cause of death in that specific patient population. Hemorrhage is the leading cause of potentially preventable death on the battlefield, with the torso identified as the primary focus [15–18]. A study by Kelly et al. examined the cause of deaths from Operation Iraqi Freedom and Operation Enduring Freedom from 2003–2004 and compared them to those of 2006. The main cause of death in potentially survivable patients was hemorrhage that contributed to 85% of the deaths [17]. Holcomb et al. reported similar significance of hemorrhage as a cause of death (82%) in the analysis of deaths in Special Operations forces over a similar time period [15]. Both of these studies also demonstrated that the majority of deaths (and opportunities for improvement) occurred in the pre-hospital environment. Subsequently, Martin et al. analyzed a series including only in-hospital deaths at a combat support hospital and found the prominence of hemorrhage related deaths to be 32%, which was second only to severe head injury at 45% [19]. In all of these studies, airway issues were not reported as a significant cause of death and particularly among preventable or potentially preventable deaths. The data is clear that in severely injured military trauma patients the key maneuver in preventing preventable mortality is to address hemorrhage control and circulation first, and that training/equipment programs should focus on this area versus airway interventions. This has led to multiple institutions adopting new protocols such as addressing circulation prior to airway and the concept of taking a patient directly to the operating room and bypassing the trauma bay. Each of these concepts will be discussed further in the next sections.

Circulation First

The adoption of "C" interventions prior to "A" interventions has already been cemented into the civilian non-trauma medical community and BLS/ACLS courses. Recent publications in the medical literature support the shift in focus of protocols moving from acquiring an airway first, to prioritizing perfusion by initiating chest compressions expeditiously especially in patients with a primary cardiac event. This has resulted in better outcomes in the reported medical literature [11–14]. Although there are large bodies of literature in the trauma setting regarding airway management with early intubation ("A") and hemorrhage control/resuscitation ("C"), there are very few studies that have compared and contrasted these two directly or evaluated differences related to their priority and sequencing by the trauma team.

One recent American Association for the Surgery of Trauma (AAST) multicenter trial conducted by Ferrada et al. did directly investigate this critical question [20]. The authors conducted a retrospective analysis of all patients that presented to

trauma centers with presumptive hypovolemic shock and undergoing intubation in the trauma bay. There were 440 patients included from 12 level 1 trauma centers. 245 (55.7%) received intravenous blood product resuscitation first, and 195 (44.3%) were intubated before any resuscitation was started. Analysis showed no statistical difference in overall mortality or other outcome measures between the two groups [20]. This study actually highlights the fact that despite the perpetuated sequence of ABC in most trauma management algorithms there are a significant proportions of trauma centers already performing "C" interventions first (over 50% in this sample). It also helps to dispel the fear that delaying airway evaluation and interventions/intubation in favor of resuscitation and hemorrhage control would result in higher mortality and worse neurologic outcomes. However, the retrospective nature and clear baseline differences between the two comparison groups limit any definitive conclusions about whether an approach focusing on "C" first is associated with improved outcomes.

A related and equally important study examined whether an aggressive posture of early intubation in the Emergency Department (ED) versus delaying intubation until arrival in the operating room (OR) was associated with any outcome differences among trauma patients requiring emergent surgery [21]. Among the 241 patients studied, 57% were intubated in the ED and 43% in the OR. Although there were no identified differences in patient demographics, injury types, initial hemodynamics, or injury severity, the incidence of post-intubation cardiopulmonary arrest was significantly higher (8% vs 0.9%) in the ED intubation cohort. Earlier ED intubation was also not associated with any benefit in terms of time to definitive surgery or hemorrhage control. This study helps to quantify the common experience of many trauma surgeons with post-intubation collapse and arrest in patients with hemorrhagic shock who undergo RSI prior to adequate resuscitation and/or hemorrhage control.

Pre-hospital/ER/OR Intubation

There is no doubt that the airway needs to be evaluated and addressed especially in an unstable trauma patient. However, the question still remains, where and when should this occur? There is significant evidence that in the bleeding or unstable trauma patient intervention in the pre-hospital setting without proper resuscitation will yield a worse overall outcome and delay the time to needed interventions or surgery. Sokol et al. reviewed the Department of Defense Trauma Registry looking at pre-hospital interventions in pediatric trauma patients, with interventions categorized into airway ("A") or circulation ("C") groups. Their analysis found that "A" interventions were associated with higher unadjusted mortality and remained independently associated with increased mortality after multivariate adjustment was performed [22]. In stark contrast, the "C" interventions were associated with a significant survival benefit among patients with major bleeding injuries. Non-military studies have yielded similar results of an increase in morbidity and mortality with pre-hospital airway interventions and intubation

[23, 24]. Some recent studies have gone even farther and investigated whether patients should have intubation delayed until the operating room [21]. In this analysis the authors were able to associate emergency department intubated patients with a higher chance of sustaining post-intubation traumatic cardiopulmonary arrest. This data suggests that control of hemorrhage and early initiation of resuscitation is critical to minimizing preventable complications related to airway interventions. Although a common theme in most trauma textbooks and ATLS for patients with major hemorrhage is to "minimize time in the ER" and transport them expeditiously to the OR, there is always some delay introduced by the ER evaluation. Several civilian trauma systems have introduced systems for "Direct to OR" trauma resuscitation where select patients are triaged directly to a fully equipped operating room for the initial evaluation and resuscitation [25–27]. This concept revolves around expeditiously getting the patient to the proper resources where control of hemorrhage and initiation of blood product resuscitation can be accomplished prior to or during the initiation of "A" interventions. The published series have demonstrated that this approach is associated with significantly shorter times to initiation of lifesaving interventions, faster hemorrhage control, and decreased mortality rates compared to predicted survival.

Recommendations Based on Data

In the pre-hospital setting, trauma patients with signs of ongoing hemorrhage or hemorrhagic shock should have "C" assessments and interventions performed before "A" interventions. "C" assessments and interventions should include tourniquets, direct pressure, and balanced resuscitations with component therapy or whole blood.

Rapid sequence intubation (RSI) in the presence of ongoing hemorrhage, cardiac tamponade, and hemorrhagic shock can produce precipitous instability and cardiovascular arrest. RSI should be delayed whenever possible until hemodynamic stabilization, and until adequate initial resuscitation is begun in a setting equipped for immediate hemorrhage control.

In most settings the reality is that the "A" and "C" assessments and temporizing interventions should be done simultaneously. However, major trauma victims are more likely to die from hemorrhage/circulation issues than airway issues, and hemorrhage and circulation concerns should take priority.

Summary of Recommendations

- In the military trauma population, the key maneuver in avoiding preventable mortality is to address hemorrhage control and circulation first. Civilian and military training programs should focus on this area versus airway interventions (Evidence quality high; strong recommendation).

- Delaying airway evaluation and interventions/intubation in favor of resuscitation and hemorrhage does not result in higher mortality and worse neurologic outcomes (Evidence quality poor; moderate recommendation).
- In the pre-hospital setting, "A" interventions are associated with higher unadjusted mortality and increased mortality after multivariate adjustments, while "C" interventions are associated with a significant survival benefit among patients with major bleeding injuries (Evidence quality moderate; moderate recommendation).
- In all cases with signs of shock, RSI should not be performed until some form of resuscitation is begun and preferably the bleeding has been controlled or will be controlled shortly (Evidence quality moderate; moderate recommendation).

Personal View of the Data

The motto of the military Joint Trauma System is "Right patient, right place, right time, right care," and really distills the essence of the recent large volume of experience with severely injured and bleeding combat casualties. With real-time analyses of data from both military and civilian trauma deaths, it became apparent that hemorrhage and hemorrhage control should clearly replace "airway" as the primary concern and focus in the pre-hospital and early in-hospital phases of care. Although lack of an airway can certainly produce rapid death, the probabilities and likelihood of survival weigh much more heavily in favor of hemorrhage control measures versus airway interventions or intubation. In reality at modern trauma centers, these assessments and interventions should be performed simultaneously and not in the strict "ABCD" sequence taught by ATLS, but the ordering is important for shaping how providers and particularly trainees think about and prioritize these problems. We also must distinguish what is particularly harmful about focusing on "A" first versus what is relatively harmless in the big picture.

This combination of bedside exam and imaging can be done in a matter of minutes and should reliably identify or rule out sites of major hemorrhage. For external hemorrhage the immediate focus should be on direct wound management, tourniquet/hemostatic dressing placement, and any other adjunct to stop the visible bleeding. For non-compressible truncal hemorrhage, the focus should be on rapid transport to a setting where operative hemorrhage control can be obtained, with simultaneous initiation of controlled resuscitation with blood products when available. In both cases, basic airway maneuvers should then be performed based on the airway assessment, but rapid sequence intubation should be avoided if possible. Only in the rare situation of a mechanical airway obstruction or significantly prolonged transport times should emergent RSI or a surgical airway be required. In all cases with signs of shock, RSI should not be performed until some form of resuscitation is begun and preferably the bleeding has been controlled or will be controlled shortly. For patients being evaluated in the ER and who clearly need operative hemorrhage control, we should avoid what I call the "ER full meal deal" where the team delays transport to perform intubation, place a central venous line and/or arterial

line, and give multiple rounds of blood products. All of these things can be delayed until the patient is in the operating room and can then be performed as the surgeon is obtaining definitive hemorrhage control. So in these authors' opinion, and in response to this chapter title, "ABC" should NOT be the standard mantra for bleeding trauma patients. The military approach with "C" assessment and interventions first should be the new standard of care and will hopefully avoid the predictable and preventable mortality and morbidity associated with premature RSI and intubation in the unstable patient.

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2 Difficult Decisions in Trauma Surgery: What Is the Clinical Impact of Whole Blood as Compared to Component Therapy in Civilian Trauma?

Lane L. Frasier, Andrew J. Benjamin, C. William Schwab, and Jeremy W. Cannon

Introduction

Whole blood transfusion was the standard of care for patients with traumatic injuries during World War I and II and the Korean War, with >600, 000 units of whole blood transfused during the Korean War [1]. In the 1960s, blood banks began separating donated blood into component therapy, prolonging storage times and allowing transfusions for specific requirements (e.g., transfusing only platelets for patients with thrombocytopenia). With this shift in blood bank practices, surgeons also changed their transfusion practices for management of patients with traumatic injuries, incorporating large volume crystalloid, followed by packed red blood cells (pRBCs) with low ratios of fresh frozen plasma (FFP) and platelets. This was accompanied by risks of coagulopathy, fluid overload, and abdominal compartment syndrome. Although damage control resuscitation practices (DCR) mitigate some of these adverse effects, even balanced component resuscitation with 1:1:1 component therapy of pRBCs to FFP to platelets yields a relatively anemic, thrombocytopenic, and hypo-coagulable product for infusion [2].

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Recently, there has been renewed interest in resuscitating patients with traumatic hemorrhage with whole blood. Proponents argue that this approach replaces all the components that lost with traumatic hemorrhage with a much lower volume of additives that contribute to ongoing coagulopathy.

During the recent conflicts in Iraq and Afghanistan, the U.S. military permitted the transfusion of whole blood when component blood products were not available in sufficient quantities to enable adequate resuscitation of patients with traumatic injuries. In the austere environment, sufficient quantities of pRBCs and FFP can be difficult to maintain, and apheresis platelets are very rarely available due to the ultra-short shelf life of this product. Accordingly, many patients received whole blood transfusion as a substitute source of platelets. Observational studies reporting non-inferiority and possibly a clinical benefit further renewed interest in use of whole blood for treating traumatic hemorrhage.

This chapter summarizes the current literature regarding whole blood transfusion for treatment of traumatic hemorrhage as compared to component therapy.

PICO Questions and Search Strategy

For this review, we developed three questions addressing a specific patient population (P), intervention (I), comparators (C), and outcomes of interest (O) (Table 2.1). A systematic review of the literature addressing these three PICO questions was performed using MEDLINE and EMBASE databases to identify English-language studies published before January 2020 using the medical subject heading (MeSH) terms and keywords. All studies including randomized controlled trials (RCTs), observational studies, and retrospective studies were evaluated. Quantitative analysis was performed using Review Manager (RevMan) 5.2 (Copenhagen, Denmark).

Relevant outcomes were identified by the chapter authors and rank ordered in terms of importance for medical decision-making and perceived patient preference. These included mortality, specific complications including multi-system organ failure (MSOF), venous thromboembolism (VTE) including deep venous thrombosis (DVT) and pulmonary embolism (PE), and transfusion reactions. Outcomes were scored from 1 (critical for decision-making) to 10 (not important for decision-making) using Research Electronic Data Capture (REDCap) hosted by the University of Pennsylvania (Table 2.2).

Table 2.1 PICO questions

Patients (P)	Interventions (I)	Comparators (C)	Outcomes (O)
Acutely bleeding patients	Transfusion with whole blood	Component therapy	Improved mortality at 24-h and 30 days
Acutely bleeding patients	Transfusion with whole blood high titer	Transfusion with whole blood low titer	Multi-system organ failure (MSOF)
Acutely bleeding woman of childbearing age	Transfusion with whole blood	Component therapy	Risk of antibody formation

Table 2.2 Rank order of outcomes of interest

Outcome	Sub-category	Score[a]
Mortality	Death from hemorrhage >24-h mortality >30-day/hospital mortality >6-h mortality	2
Any complication	MSOF > respiratory > renal > infectious > VTE	4
Total blood product requirement		4
Any transfusion reaction		5
Hemolysis		6
Volume of anticoagulant		6
Expense		6
Transfusion logistics		8

MSOF multi-system organ failure, *VTE* venous thromboembolism
[a]1–3 = Critical for decision-making; 4–7 = Important but not critical for decision-making; 8–10 = Less important for decision-making, of lower importance to patients

Results

Results for Mortality (PICO 1)

In the acutely bleeding trauma patient, does transfusion with whole blood compared to component therapy result in improved mortality at 24-h and 30-days?

Qualitative Synthesis

A meta-analysis by Crowe et al. [3] identified 12 studies (total of 8431 patients) evaluating mortality outcomes at 24 h, 30 days, or in-hospital. They identified significant heterogeneity of populations, settings, interventions, and studied outcomes, and found no differences in mortality when patients received whole blood versus component therapy.

Cotton et al. [4] report on a randomized controlled pilot trial of modified whole blood (leukoreduced, resulting in platelet depletion) compared to component therapy for civilian trauma patients with severe trauma and predicted to require massive transfusion.

Seheult et al. [5] described a retrospective analysis of 135 civilian trauma patients who received low-titer whole blood transfusion (LTWB, defined here as) who were propensity-matched 1:1 to civilian trauma patients who received ≥1 unit pRBC during their first 24 h after admission. The authors found no significant differences in 24-h or in-hospital mortality between patients receiving component therapy without LTWB compared to patients who received LTWB (6-h mortality 3.7% vs 3.0%, $p = 0.74$; 24-h mortality 12.6% vs 8.9%, $p = 0.33$; in-hospital mortality 18.5% vs 24.4%, $p = 0.24$).

Jones and Frazier [6] describe a retrospective analysis of the 2009 National Trauma Data Bank to perform logistic regression and identify predictors of mortality. Analyzing 1745 patients ages 18–45 with major trauma, defined as Injury Severity Score (ISS) > 25, the authors found that higher ISS, longer pre-hospital transfer time, and transfusion with component blood products were independently associated with mortality. Component therapy was associated with a higher odds ratio (3.164, 95% CI 1.314–7.618, $p = 0.01$) of overall mortality compared to whole blood transfusion. Neither 6-h nor 24-h mortality was reported in this analysis.

Nessen et al. [7] performed a retrospective analysis of 488 military trauma patients who received fresh whole blood (FWB) in addition to pRBC and fresh frozen plasma (FFP) in Afghanistan, where platelet component therapy was not readily available, compared to patients who did not receive FWB. They found that patients who received FWB in addition to pRBC and FFP component therapy had lower in-hospital mortality (OR 0.096, 95% CI 0.02–0.55, $p = 0.008$) despite having higher ISS. A subset analysis of patients who received uncrossmatched Type O FWB (N = 46) compared to type-specific FWB (N = 48) found no difference in mortality. Neither 6-h nor 24-h mortality was reported in this analysis.

A similar retrospective analysis by Auten et al. [8] yielded conflicting results. This smaller analysis of 61 US military trauma patients with ISS ≥ 15 was performed, evaluating outcomes for patients who received component therapy with pRBC and FFP (N = 35) vs component therapy plus FWB (N = 26) found no survival benefit at 24 h or 30 days for patients receiving component therapy plus FWB using logistic regression (OR 0.81, 95% CI 0.08–7.82).

Perkins et al. [9] performed a retrospective analysis of military trauma patients in Iraq requiring massive transfusion, defined as ≥10 units of blood products in 24 h and compared patients receiving component platelets (N = 284) vs those receiving FWB (N = 85). Using multivariate regression, the authors found no difference in survival between patients receiving component platelets vs FWB as part of their massive transfusion resuscitation at 24 h ($p = 0.06$). Mortality was not reported at 6 h in this analysis.

Spinella et al. [10] report a retrospective analysis of military personnel with traumatic injuries between 2004 and 2007, who received whole blood, but not component platelets, in addition to component therapy with pRBC and FFP (N = 100), compared to patients who underwent component therapy with pRBC, FFP, and platelets (N = 254). Reported outcomes included 24-h and 30-d mortality. Using multivariate regression, use of whole blood, and increasing volumes of whole blood transfusion, were associated with improved 30-day survival.

Yazer et al. [11] reported outcomes for male patients with traumatic injuries and hemorrhage requiring blood transfusion, comparing outcomes for 47 patients who received 1–2 units of whole blood to 145 historical controls who required transfusion within 24 h of admission. They reported no difference in mortality for patients receiving 1–2 units of whole blood (36%) compared to historical controls (28%), $p = 0.27$.

Kauvar et al. [12] evaluated 281 military trauma patients who received blood transfusion in 2003. Thirty-six of these patients received FWB transfusion. Although

mortality data were missing for 6% of patients not receiving FWB, overall mortality did not differ between groups. Mortality was not reported at 6 or 24 h in this analysis.

Zhu et al. [13] review outcomes for severely injured trauma patients requiring blood products pre-hospital. They report on 25 adult (22 traumatically injured) patients who received whole blood en route to hospital. They report gross mortality rate (36%) including pre-hospital deaths, and compare to historical controls (62%). Ho and Leonard [14] review 353 patients who received massive transfusion protocol, 77 of whom received whole blood during their massive transfusion. Only 25% of patients in the massive transfusion group overall carried a diagnosis of trauma, however (12% of the whole blood recipients and 30% of standard MTP).

Quantitative Synthesis

Five articles met criteria for quantitative analysis of 24-h mortality (Fig. 2.1), and 11 articles met criteria for quantitative analysis of 30-day or in-hospital (Fig. 2.2) mortality. Both are sub-divided by intervention with stored whole blood, common in civilian and military settings, and fresh whole blood, used nearly exclusively in the military setting. Interventions with stored whole blood demonstrate low heterogeneity, while interventions with fresh whole blood had a moderate degree of heterogeneity. The combined effect showed no benefit with a low degree of heterogeneity.

Grading the Evidence

The overall quality of the evidence was Low (30-day mortality) to Very Low (6-h and 24-h mortality) due to the retrospective nature of most data, high risk of bias, and imprecision of reported outcomes. Funnel plots evaluating risk of publication bias are seen in Fig. 2.3. There is the potential for publication bias for 24-h mortality, indicated by the lack of publications occupying the lower

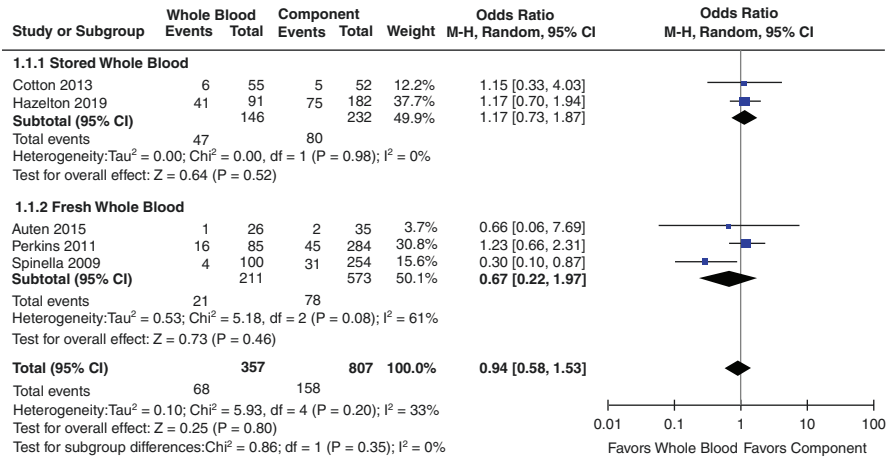

Fig. 2.1 Quantitative analysis of 24-h mortality (PICO 1). Articles are sub-grouped by intervention using stored whole blood or fresh whole blood. *CI* Confidence Interval

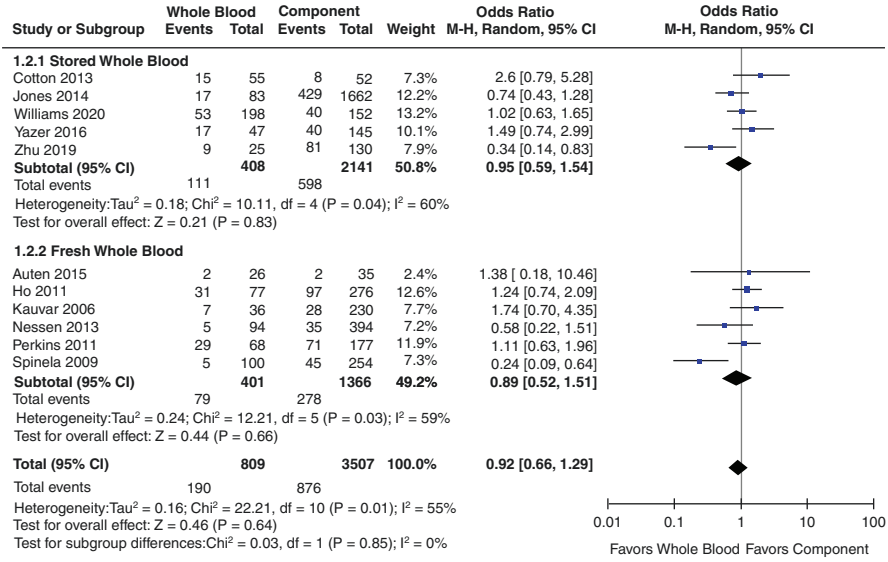

Fig. 2.2 Quantitative analysis of 30-day mortality (PICO 1). Articles are sub-grouped by intervention using stored whole blood or fresh whole blood. *CI* Confidence Interval

right corner of the plot. There was a low likelihood of publication bias for 30-day mortality.

Results for Any Complications (PICO 2)

For the acutely bleeding trauma patient, does transfusion with whole blood with high vs low antibody titer result in increased multi-system organ failure (MSOF) at 30 days?

Qualitative Synthesis

We identified no articles that addressed this question. There is currently no standard definition of "high" or "low" titer whole blood, and individual institutions and blood banks must determine their own standards for the definition of "low" titer [15] given the availability of donors and the risks of wasting donated blood versus the risks of antibody-mediated transfusion reaction. Additionally, there were few articles that evaluated MSOF after whole blood transfusion. We therefore amended our search to identify any complications associated with whole blood transfusion.

Seheult et al. [5] evaluated Acute Kidney Injury (defined as any of the following: increased creatinine 1.5x over baseline, absolute increase in creatinine ≥0.5 mg/dL, or any post-admission creatinine ≥4.0 mg/dL) and bacteremia, defined as any positive bacterial blood culture within 7 days of admission. Auten et al. [8] evaluated complications including coagulopathy, any infection, blood

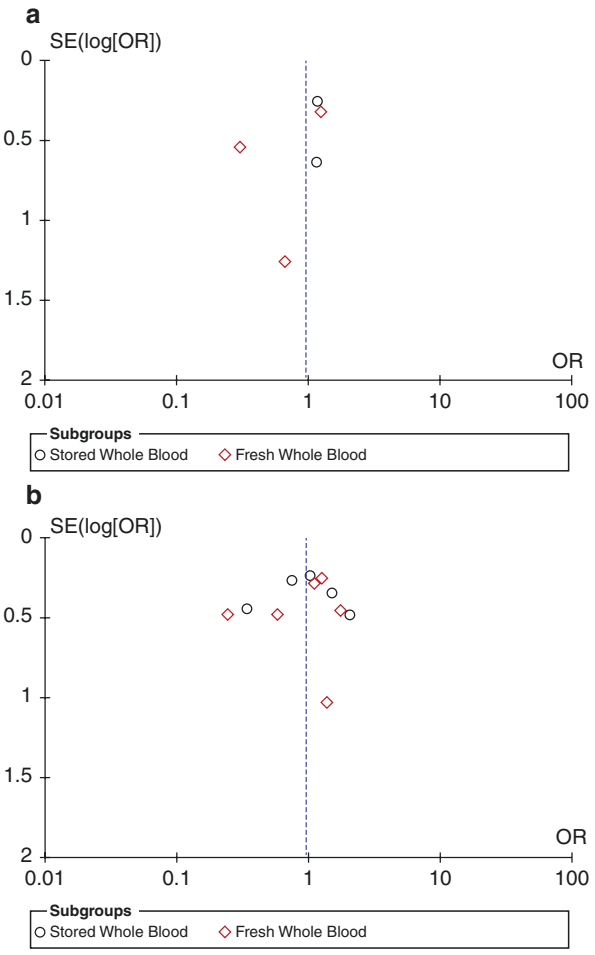

Fig. 2.3 Funnel plots analyzing risk of publication bias for 24-h (**a**) and 30-day (**b**) mortality (PICO 1). Articles are sub-grouped by intervention using stored whole blood or fresh whole blood

clotting, transfusion reaction, and Acute Respiratory Distress Syndrome (ARDS). Perkins et al. [9] evaluated complications including ARDS, MOFS, infection, embolic event. Spinella et al. [10] evaluated complications including DVT, PE, myocardial infarction (MI), cerebral stroke, ARDS, and renal failure, which were not defined in the manuscript.

Quantitative Synthesis

Cotton [4], Perkins [9], and Spinella [10] included data appropriate for meta-analysis of complications data (Table 2.3). Overall, there was a trend toward increased complications with use of whole blood transfusion (Fig. 2.4). This increase in reported complication with use of whole blood may represent survivorship bias, driven by the increased survival reported with whole blood transfusion by Spinella [10].

Table 2.3 Summary of Complications Associated with Transfusion

	Respiratory[a]		Renal Failure		MSOF		Thrombotic[b]		Infectious	
	WB	Comp	WB	Comp	WB	Comp	WB	Comp	WB	Comp
Cotton 2013	11/78	15/84	1/39	1/42	3/39	4/42	NR	NR	10/78	8/84
Perkins 2011	16/85	21/284	NR	NR	9/69	18/239	9/85	37/284	22/85	71/284
Spinella 2008	7/100	7/254	8/100	7/254	NR	NR	23/400	37/1016	NR	NR

ARDS Acute Respiratory Distress Syndrome, *MSOF*, Multi-System Organ Failure, *WB* Whole Blood, *NR* Not Reported

[a]Respiratory complications include acute respiratory failure and acute respiratory distress syndrome (ARDS)

[b]Thrombotic complications include deep venous thrombosis (DVT), pulmonary embolism (PE), myocardial infarction (MI), and stroke

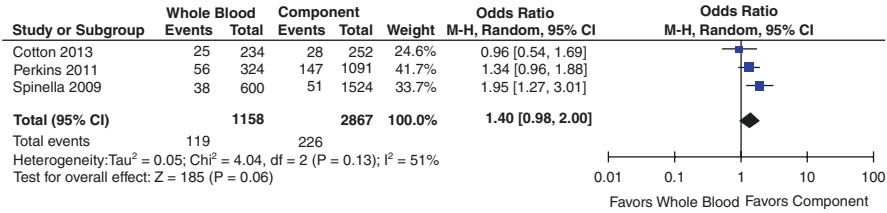

Fig. 2.4 Forest plot analyzing complications associated with whole blood transfusion versus component therapy

Grading the Evidence

The overall quality of the evidence was Low for all complications evaluated due to the retrospective nature of most data, high risk of bias, and imprecision of reported outcomes.

Results for Whole Blood Transfusion in Women of Childbearing Age (PICO 3)

For the acutely bleeding trauma patient who is a woman of childbearing age, does transfusion with whole blood compared to transfusion with component therapy result in increased risk of antibody formation?

Qualitative Synthesis

We found no articles evaluating this question. Most data on whole blood transfusion originate from military studies in which most patients are male. In civilian environments, women have been excluded from the only RCT performed to date.

Recommendations Based on the Data

At this time, there is no evidence that resuscitation with whole blood as compared to component therapy decreases 24-h or 30-day mortality for the acutely bleeding trauma patient. However, this analysis is limited by low quality of evidence and heterogeneity in the studies which are predominately retrospective in nature. Future prospective studies in this area are needed to fully evaluate the potential benefit of whole blood resuscitation for acutely injured, bleeding patients. In addition to 24-h and 30-day or in-hospital mortality, future studies should also assess 6-h mortality. This shorter endpoint likely represents a more ideal endpoint for evaluating hemostatic interventions such as whole blood as compared to 24-h or 30-day mortality as improvements in 6-h mortality would suggest reduced coagulopathy and hemorrhage as a cause of death.

At this time, there is insufficient evidence to support the use of whole blood for treatment of traumatic hemorrhage when considering common complications including multi-system organ failure, respiratory complications including ARDS, renal failure, infectious complications, and VTE events. The possible increase in complications reported with use of whole blood may be due to increased survivorship, and future work evaluating mortality benefit (PICO 1) must also evaluate the sequelae of any mortality benefit by studying the complications seen in surviving patients.

There are insufficient data to recommend for or against use of whole blood transfusion in women of childbearing age requiring blood transfusion for traumatic injuries. Future work must include evaluation of the potential for formation of anti-Rh antibodies to provide clinicians and patients with evidence to weigh the potential benefits of whole blood transfusion against the potential risks for Rh-negative patients to develop antibodies and develop maternal-fetal Rh factor incompatibility with potential future pregnancies.

Summary of Recommendations

- There is no evidence that resuscitation with whole blood as compared to component therapy decreases 24-h or 30-day mortality for the acutely bleeding trauma patients (evidence quality low to very low; weak recommendation).
- There is insufficient evidence to support the use of whole blood for treatment of traumatic hemorrhage when considering common complications including multi-system organ failure, respiratory complications including ARDS, renal failure, infectious complications, and VTE events (evidence quality low; weak recommendation).
- There are insufficient data to recommend for or against use of whole blood transfusion in women of childbearing age requiring blood transfusion for traumatic injuries. We found no articles evaluating this question (evidence quality very low; weak recommendation).

Personal View of the Data

In this systematic review, we assess the potential benefits of blood product resuscitation with whole blood as compared to component therapy in acutely bleeding patients. The re-emergence of this approach after many years of component-based resuscitation represents a potential opportunity to address one of the most intractable challenges in trauma surgery: potentially preventable death from hemorrhage. However, understanding the appropriate indications for whole blood resuscitation, the optimal balance between this limited resource and more readily available components, and the potential complications will take years to unravel through careful, deliberate, prospective analysis. Regarding the monetary aspects of the "cost" of whole blood, this too remains relatively uncharted territory. Limited international data indicates a potential cost savings associated with whole blood utilization [16], assuming the same or perhaps fewer units of whole blood would be required for a given resuscitation. Going forward, cost and charge data should be included in the study protocols to more fully understand all aspects of the optimal practice of hemostatic resuscitation in the modern era.

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Helicopter Emergency Medical Services in Trauma

3

Robel Beyene and Oscar Guillamondegui

Introduction

The earliest use of civilian helicopter EMS (HEMS) was based on perceived success in combat settings, including the Vietnam War and the Korean Wars [1]. Today, HEMS is a fixture in the trauma systems of most developed nations. Despite its widespread use, helicopter EMS utilization is still controversial in trauma, with debate ongoing about where it confers the greatest benefit. Defenders argue that it decreases transport time to definitive care and improves mortality, especially in polytrauma patients. Detractors argue that it is overused, prone to over-triage, costly, and potentially unsafe to the crew and the patients [2, 3]. They also note that helicopters are generally a late indicator that a trauma system is well established, which may independently account for the benefits attributed to HEMS [4].

Reasonable limitations in study design further complicate the ability to accurately study the benefits of HEMS. Variations in crew, first responder scope of practice, helicopter or ambulance design, base distribution, population density, trauma center location, and geography make findings difficult to generalize and apply broadly [5]. Practical and ethical limitations on designing a randomized, controlled trial also limit the quality of the data. The only significant systematic review comparing HEMS with ground EMS (GEMS) identified such weakness in the literature and heterogeneity of effect and methodology as to make composite benefit impossible to determine [1]. (Table 3.1)

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Table 3.1 PICO table

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with traumatic injuries	Helicopter transport to level 1 trauma center	Ground transport to level 1 trauma center	Mortality, costs

Search Strategy

A literature search of English language publications from 2010 to 2020 was used to identity published data on helicopter transport to level 1 trauma centers after traumatic injury. (Table 3.2) Databases searched were PubMed and Cochrane Evidence-Based Medicine. Terms used in the search were "helicopter transport/trauma," "helicopter/trauma," "aeromedical transport/trauma," "air medical transport/trauma," "HEMS/trauma," "Helicopter Emergency Medical Transport/trauma." Due to the generally poor quality of data, the reference list from some of these articles was used to find similarly appropriate articles. Articles were excluded if they only addressed pediatric patients, helicopter-related traumatic injuries, or were conducted outside the USA or Canada. Twenty-nine cohort studies, two systematic reviews, and one guideline were included in our analysis. (Table 3.3).

Results

Assuming appropriate patient selection, helicopter EMS reduces mortality in trauma patients. Even critics of HEMS who argue about cost-benefit ratios and over-triage generally concede that it reduced mortality in a subset of severely injured patients. A 2010 study by Brown, a prolific lab in this field, showed that patients transported by HEMS were more severely injured (ISS > 15), have more serious head injuries (GCS $\leq$ 8), and have more abnormal physiology on arrival (SBP < 90, RR > 29 or < 10), but still show a survival benefit (AOR = 1.22, 95% CI, 1.18–1.27; P < 0.01) [6]. Hannay found that even though patients transported by HEMS had higher Injury Severity Scores (ISS) and lower GCS, were subjected to more interventions and operations, and were more likely to receive blood than patients transported by other means, they still had reduced hospital mortality (OR = 0.41, P = <0.001) [2]. Galvagno used the National Trauma Data Bank (NTDB) to show an increased odds of survival in patients taken by helicopter transport to a level I trauma center (OR = 1.16, ARR = 1.5%; 95% CI, 1.14–1.17; P < 0.001) which remained after propensity matching [7].

Transport Time

Rhinehart showed that the incremental increase in the residence-to-helicopter base distance was associated with an incremental increase in mortality, at approximately 0.5% increased risk of death per additional mile, though this did not bare out after

Table 3.2 Evidence regarding helicopter transport in trauma and the effect on mortality

Author (year)	N	HEMS Mortality (%)	GEMS Mortality (%)	HEMS compared to GEMS Survival to Discharge AOR (95%CI; P)	HEMS compared to GEMS Odds of Mortality (AOR; 95%CI; P)	Notes	Quality of evidence
Galvagno (2012)	159,511	12.7	11	OR 1.16 (1.14–1.14;P < 0.001) OR 1.15 (1.17–1.17;P < 0.001)	–	Level I center Level II center	Low
Stewart (2011)	10,184	10.1	7.2	–	*HR 0.67 (0.54–0.84)*	2 week mortality. HR, not OR.	Low
Von Recklinghausen (2011)	2164	6.46	5.5	OR 1.87 (0.8–1.7; P.4)	–	*NOT SIGNIFICANT*	Low
Ryb (2012)	192,422	6.2	3.9	AOR 1.78 (1.65–1.92;P < 001)	–		Low
Brown (2016)	193,629	8	4	AOR 1.48 (1.44–1.52;P < 0.001)	–		Low
Brown (2010)	258,387	7.5	4.4	AOR 1.22 (1.18–1.27;P < 0.01)	–		Low
Zhu (2018)	1194	7.7	5.3	AOR 2.69 (1.21–5.97)		75.3% propensity matched cases	Low
Rose (2012)	1443	12	3	–	–	Only ISS stratified results reported	Low
Shaw (2016)	4552	4.1	1.9	–	*AOR 0.7 (0.3–0.9)*	OR of death, not survival.	Low
Malekpour (2015)	8191			OR 1.57 (1.03–2.4;P = 0.036)			Low
Bekelis (2015)	99,796	12.01	7.81	AOR 1.95 (1.81–2.1;P ≤ 0.001)			Low
Sullivent (2011)	56,744	6.8	4		AOR 0.61 (0.54–0.69;P < 0.0001)	OR of death, not survival.	Low
Hannay (2013)	14,440	15	12		AOR 0.41 (0.33–0.49;P < 0.001)	OR of death, not survival.	Low
Chen (2017)	153,729	10.8	10.5	AOR 1.22 (1.03–1.45;P = 0.02)			Low
Rinehart (2013)	244,293	9.1	6.4	AOR 1.0 (0.997–1.003;P < 0.001)		Adjusted OR favors GEMS	Low

Table 3.3 Recommendations on use of helicopter transport in trauma

Advantage of HEMS	Grade of evidence	Recommendation	Strength of recommendation
Improved mortality	Low	HEMS should be utilized for trauma patients meeting appropriate anatomic, physiologic, and situational criteria[a]	Weak recommendation

[a]No guideline exists meeting all of these criteria that can be generalized—each center or municipality would have to create and regularly re-evaluate their own guidelines regarding mortality and cost

case-mix adjustments (adjusted OR, 1.002; 95% CI; 0.997–1.006; P = 0.40) [8]. However, as the residence-to-trauma center distance passed 11 miles, the residence-to-helicopter base distance retained a durable incremental increase in mortality of 1% per additional mile. This was considered clinically relevant at 20 miles (adjusted OR, 1.006; 95% CI, 1.000–1.011; P = 0.05) and did not vary with injury severity score or hypotension, but it did require at least 1 helicopter base within 25 miles of the residence (adjusted OR, 0.77; 95% CI, 0.59–1.00; P = 0.05), with no increased benefit with more bases in that radius. The study only indirectly measures transport time and uses patient residence zip code as a proxy for the scene of the injury, but it does indicate the importance of the distribution of helicopter bases in reducing mortality.

Geography, and its effects on transport time, may contribute to the decision to transport trauma patients by ground or air. Remote scene and difficult terrain access are very different between helicopters and ground transport, but even urban geography can alter outcomes. Brown demonstrated increased in-hospital survival and discharge home with HEMS despite longer prehospital times, with the magnitude of treatment effect that varied across different regions of the USA [9]. This demonstrates that prehospital time is not only dependent on distance but also topography, triage time, weather, infrastructure, EMS accessibility, and traffic. However, von Recklinghausen's retrospective review showed that even in rural areas where transport times are accounted for in deciding the route of transport, survival benefit might only be seen in patients with an ISS between 1–8 (OR 0.122, 95%CI, 0.002–0.764). While this likely represents the limitation of a single-center study, the paper could not identify a survival benefit in any other ISS groups either [10]. Zhu showed in another single-center study that there was a significant survival advantage to HEMS over GEMS in the rural setting (AOR = 2.69; 95% CI = 1.21–5.97). Although other, single-center trauma studies contradict the role of geography in any setting [11, 12].

Time as a comparator between modes of transport may be difficult to incorporate into a retrospective study due to the non-simultaneous nature of calls to helicopter and ground transport. In the Stewart paper, there was a mean difference of 9.3 min with a standard deviation of ±6.4 min [13]. Pham, Puckett, & Dissanaike did show that HEMS response with less than 10 min of on-scene time had decreased mortality compared to longer on-scene times, though there was no comparison against GEMS transport. There is evidence that this may not make any difference [14]. Newgard showed that there was no indication of increased mortality with increasing times in

the field, though no distinction between modes of transport is made [15]. In the Stewart paper, there was, somewhat confusingly, a protective effect of increased distance and increased time on mortality [13]. Finally, another article by Brown shows that, when stratified by equal prehospital times, the survival benefit attributed to HEMS is concentrated between 6 and 30 min [16].

Triage

Some studies have argued that HEMS is non-beneficial by showing that a large population of patients arriving by helicopter failed to meet admission criteria, and other centers have shown stable mortality before and after the institution of HEMS [2]. Galvagno argued in a systematic review that the benefits of HEMS could potentially include "physician-adjudicated launching criteria" and "centrally coordinated launching algorithms," as well as access to areas inaccessible by traditional means of transport [1]. Hakakian also showed mortality between HEMS and GEMS was not significantly different, even with equivalent transport time. This still represents an advantage in HEMS since those patients were sicker (higher ISS, more operations, and more admissions greater than 24 h) [17, 18]. Talving was unable to identify an improved overall adjusted survival in trauma patients transported by HEMS rather than GEMS in their single-center study [19].

Over-triage is an ongoing concern in the use of HEMS. In a study by Dhillon, the median ISS of HEMS transported patients decreased over time, and the proportion with an ISS over 16 fell by13.7% [20]. Furthermore, HEMS transport of patients with minor injuries (ISS <9) was roughly 30% and up-trending. Even studies showing a benefit to HEMS identify over-triage, including HEMS transport of low ISS patients and discharge of patients within 24 h of arrival [6]. This may undermine arguments of improved or even equivalent survival between GEMS and HEMS transport.

Certain injuries may specifically benefit from HEMS. Bekelis used a large cohort from NTDB to show that patients with traumatic brain injuries (TBIs) who are transported by helicopter to a level I center have increased survival after propensity matching (OR = 1.88, ARR = 5.93; 95% CI, 1.74–2.03), which corresponds to a number needed to treat of 17 [21]. This suggests that appropriate triage at the scene may lead to improved outcomes if identification of TBIs guides the choice of HEMS over alternatives. However, Bulger was unable to find a survival benefit of HEMS in a TBI cohort (OR = 0.91, 95% CI = 0.63 to 1.33) [4].

While the importance of appropriate patient selection is agreed upon, ISS metrics and other hospital measures are not typically available at the scene and are more germane to review than the on-the-scene utility. Stewart stratified patients by metrics that were available in the field (e.g., demographics, vital signs, mechanism of injury, anatomic triage criteria, distance) and found that patients with a Revised Trauma Score (RTS) between 3–7, indicating some abnormality in their vital signs, had the greatest reduction in mortality associated with HEMS compared to GEMS (HR = 0.61, 95% CI = 0.46 to 0.82) [13].

Methods to identify patients who most benefit from HEMS have led to some tools being created to standardize the selection, such as the Air Medical Prehospital Triage (AMPT) score [22]. Using the NTDB, Brown validated a set of mostly objective scene criteria to triage patients to either helicopter or ground transport, which showed a survival benefit of appropriately utilized HEMS (AOR 1.28; 95% CI 1.21–1.36, $P < 0.01$). This scoring system takes into account GCS, RR, unstable chest wall fractures, suspected hemo or pneumothoraces, paralysis, and multisystem trauma in deciding the appropriate form of transport. While the AMPT criteria are all identifiable in the field, situational criteria (traffic, geography, distance, etc.) are still not into account. Thomas, in a systematic review, strongly recommended field triage criteria that included not only physiologic and anatomic criteria, but also situational criteria, though they acknowledge the strength of their recommendation, despite low-quality evidence, is to minimize under-triage rather than specific evidence of validated criteria [23].

Scope of Practice

Studies that argue against the "transport time" model of improved mortality in HEMS often site crew expertise as the factor that confers a mortality benefit in HEMS [1, 18]. McVey showed HEMS transport reduced mortality (relative to predicted mortality) without significant differences in prehospital time [18]. Ryb and Brown indicate that some other factor besides transport must be contributing to outcomes [16, 24]. HEMS flight medics and nurses generally have to demonstrate significant previous experience (often in critical care) before being chosen. They then undergo further specialty training, including diagnostic and procedural training. Flight crews may also include respiratory therapists and, in some settings, physicians [7]. The specialty training and team diversity of flight crews leads to greater diagnostic and procedural capabilities, including medication administration, blood product use, intubation, and emergency procedures, such as emergency surgical airways, reduction of fractures and dislocations, and decompression of tension pneumothoraces [6]. Successful intubation has been specifically identified as a benefit of prehospital management by a HEMS crew, as they are generally more experienced at advanced airway procedures than GEMS crews [13]. The impact of crew training is not specifically addressed in the reviewed papers, however, as it is not captured by the databases used in these studies.

Cost and Safety

The cost of air ambulance services is high and has been increasing. In some states, the base rate can be roughly $6500 to $14,000, with additional expenses accrued per mile and up to $4.5 million per institution [2, 3, 21]. Reimbursement by Medicare and Medicaid leaves a significant gap in coverage that will fall upon the patient [2]. Even in patients who benefit from HEMS, this can contribute to skyrocketing healthcare costs which can be life altering. Among patients who have no clinical

benefit, such as those who have low ISS or are discharged within 24 h of admission, this devastating cost can come with no upside. Brown showed that relying on first responder judgment for choosing the method of transport in trauma patients did not become cost-effective until a threshold at or above $310,000 per quality-adjusted life years (QALY), which is much higher than the widely accepted numbers of $50,000–$100,000/QALY [3]. Delgado found that HEMS would have to demonstrate a relative risk reduction of 15%-30% (RR 0.85 to 0.70) to cost less than $100,000/QALY or $50,000/QALY, respectively [25]. To accomplish this, HEMS would have to demonstrate improvement in disability outcomes or reduction in the number of minor injury patients transported by helicopter.

While neither HEMS nor GEMS crashes are frequent, they do occur. In the supplement, Brown identified a fatal crash per mile traveled rate of 1.6×10^{-7} for HEMS and 8.0×10^{-8} for GEMS; while that number is half that of the HEMS risk, and helicopters are often chosen specifically for longer distances, the clinical risk is somewhat trivial [3].

Recommendations Based on the Data

Substantial variability in methodology and low to low-quality data make it very difficult to make strong, specific recommendations regarding helicopter transport of trauma patients with regard to minimizing mortality or cost. Even though most, but not all studies, agree that HEMS does lead to improved adjusted odds of survival in a subgroup of trauma patients, no determination can be made about which subgroup would most benefit. However, the limitations on the data are unlikely to be overcome in the future as no methodology can overcome the logistical and ethical limitations of the observational studies that have already been published. With that in mind, we would weakly recommend the use of helicopter transport of trauma patients who meet appropriate anatomic, physiologic, and situational criteria, though no scoring with all of these criteria has been validated. (Table 3.3) Furthermore, the addition of situational criteria will be local and will require regular re-evaluation of the outcomes generated to refine better.

Summary of Recommendations
Trauma patients that meet anatomic, physiologic, and situational criteria should be triaged to HEMS transport. (Evidence quality low; weak recommendation).

Personal View of the Data

Overall, there are very few recommendations that can be made by the data. Anecdotally, the use of helicopter transport seems necessary. The safe, rapid transport of the injured patient to the appropriate level trauma center is imperative to

afford excellent outcomes. There are a couple of issues that do need to be addressed moving forward —first, appropriate field assessment to limit helicopter transport over-triage. Utilizing physiologic criteria and analyzing the at-risk under-triaged cohort will be vital to accurate transport mechanisms, especially in rural and austere environments. Second, the costs associated with helicopter transport can be as life altering to the trauma patient as their injury pattern. Working with CMS and other invested groups to develop cost-management strategies with helicopter transport systems may improve this situation. Finally, developing universal protocols for both helicopter and ground EMS teams to utilize the most appropriately trained, adequate transport type and best triage methods to ensure secure transfer of the injured patient to the correct trauma center should be warranted.

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4 Futility of Care in Hemorrhagic Shock: When Prolonging the Massive Transfusion Protocol Is of No Benefit

Rafael Tolentino, Timothy J. Holleran, and Laura S. Johnson

Introduction

Hemorrhage from traumatic injury is the number one cause of preventable death and is second only to traumatic brain injury in overall mortality [1]. The replacement of blood products in large volumes, or a "massive transfusion," dates back to the 1970s when separation of donated whole blood into its component parts became commonplace, but even into the 1980s, mortality from hemorrhagic shock requiring massive blood transfusion was greater than 80%. Knowledge gained from combat (Iraq and Afghanistan) lead to a new resuscitation strategy, termed *damage control resuscitation.* This approach focused on earlier and more balanced, hemostatic resuscitation with transfusion ratios closer to the 1:1:1 ratio of whole blood while simultaneously minimizing crystalloid use.

Over the past two decades, there have been great strides in the evolution of managing hemorrhagic trauma. Protocols on the appropriate allocation of blood products in emergency situations were developed to help triage these limited resources to maximize their benefit and concurrently control rapidly ballooning healthcare costs. The adoption of a massive transfusion protocol helped decrease the mortality rate of hemorrhagic shock to 45–50% [2, 3]. Subsequently, larger randomized

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clinical trials confirmed additional decreases in mortality with this approach [4, 5]. The 2015 Pragmatic Randomized Optimal Platelet and Plasma Ratios (PROPPR) trial confirmed that balanced resuscitation with packed red blood cells, plasma, and platelets in a 1:1:1 ratio could reduce mortality to as low as 12% [5]. Given these outcomes, it is evident why almost all academic trauma centers in the USA have instituted massive transfusion protocols, though uniformity in definition and application is still lacking [6].

The most consistent definition of massive transfusion (MT) in the literature is ≥10 units of red blood cells [RBCs] in 24 h, roughly equivalent to one patient blood volume for an average-weight person. However, this cutoff has never been validated. An updated definition which more accurately reflects mortality outcomes has been suggested: transfusion requirement greater than or equal to six RBC units in 24 h [7]. But as this traditional focus on static volumes over fixed times can miss dynamic changes in patient status, alternative definitions incorporating both rate and volume of transfusion have emerged to provide a better predictor of mortality. These run the gamut of varying quantities of red blood cell units or other blood components given in a shorter time span (30–60 min) to the documentation of observed rapid bleeding [8, 9]. The lack of consensus continues to drive ambiguity in assessing data related to massive transfusion outcomes.

Futility in the Context of Massive Transfusion Protocol

Outside of devastating CNS injuries and nonsurvivable injuries in which timing of death is in minutes, advances in the prehospital and trauma systems of care to address the classic trimodal distribution of trauma death has made it harder to identify a clear cutoff at which point the medical care being provided to a patient is no longer in aid of survival [10]. Gunst and colleagues have actually suggested that the classic trimodal distribution has been shifted to a bimodal distribution, with most deaths occurring either immediately or within 60 min of injury [11]. Thus, patients who are supported beyond those first few hours could reasonably be expected to survive. Keeping in mind the consensus statement of the Society of Critical Care Medicine's Ethics Committee on Futility, which states that treatments should be defined as futile only when they will not accomplish their intended goal, there is some consensus among authors that the futility threshold is resuscitation when the likelihood of mortality exceeds 95%, though universal agreement on this definition is lacking [12, 13].

In the context of hemorrhagic shock, defining futility is of paramount importance as this determination could theoretically assist the clinician's decision to activate or cease a massive transfusion by providing an assessment of benefit and outcome adjustment. (Table 4.1) Because blood is one of the most important and limited resources available in a trauma center, setting a limit on MTP in the critically injured patients if a point of futility can be determined is most consistent with the ethical principle of justice. Therefore, identifying limits of MTP

Table 4.1 PICO Question

Patients	Intervention	Comparator	Outcomes
Massively transfused trauma patients	Massive transfusion protocol (MTP)	Cessation of MTP	Transfusion requirements, mortality

and risk factors beyond which survival is not expected could assist the surgeon in making such decisions and could avoid unnecessary expenditure of valuable resources [14].

Search Strategy

Research on this topic is limited. A search strategy using the terms [(futility) AND (massive transfusion)] on PUBMED identified a total of eighteen papers, of which seven were relevant to this topic. Additional papers on mortality estimates in trauma were identified using the search term [(massive transfusion mortality estimate)]. Results are summarized below.

Markers of Futility in the General Trauma Population

The simplest potential means of determining if a massive transfusion had reached futility would be if there was a concrete number of units transfused above, which survival was impossible. Velmahos and colleagues, in a retrospective review of 141 critically injured patients who underwent an emergency operation at a large-volume, academic level I trauma center, attempted to determine if an actual number of RBC units transfused was predictive of mortality [14]. The study focused on the preoperative and intraoperative period that follows emergency admission for critical injuries requiring surgical interventions. Ultimately they found that the number of RBC units transfused did not differ significantly between survivors and non-survivors, with one survivor receiving 68 RBC units, and recommended continuing short-term care even at large transfusion volumes [14]. Criddle similarly used a single-institution database of 13,000 patients to look at survival after large-volume blood transfusions, and found no difference in groups of patients who received 50–74 units, 75–99 units, or more than 99 units [15]. However, while multiple studies suggest there is a critical number of PRBCs transfused above which mortality increases significantly, all conclude that there is an acceptable enough survival rate to warrant continued interventions, including additional tranfusions [16–20]. The most recent study to evaluate units of the blood relative to mortality suggests transfusion beyond 80 units may be considered futile [21]. Of course, it has been proposed that PRBC unit transfusion quantities would actually be lower in non-survivors due to death before appropriate ratios of transfusions were achieved, but this was addressed in a 2012 study by Brown et al. that demonstrated high ratio resuscitations benefits were independent of survivor bias [22].

There have been a number of studies that have attempted to define objective endpoints of MTP such as lab abnormalities or changes in physiologic parameters. Small, single-center retrospective reviews have looked at specific variables, namely markers of acidosis. Tremblay looked at the base deficit in a cohort of patients presenting with extreme base deficits (less than −20) on arrival at their institution and identified that while the mortality in that cohort was significant in the first 24 h (Blunt 85% / GSW 85% / Stab 50%), if patients survived to 24 h that mortality dropped substantially (Blunt 27% / GSW 21% / Stab 10%) [23]. Of note the blunt cohort of patients in this group only received an average of 8 units of PBRCs; however the penetrating mechanism patients received 10–20 units consistent with MT definitions [23]. Katirai and colleagues specifically analyzed the ability of initial abnormal arterial blood gas (ABG) to predict futility in hemorrhagic shock by comparing the first three pH values of a set of critically ill bleeding trauma patients [24]. They found that while "non-survivors" had an average initial pH of 7.15 and no "survivor" had a pH below 7.0, 8.7% of patients with an average initial pH less than 7.15 did survive [24].

Asensio and colleagues evaluated just over 500 patients who received at least six units of PRBCs, with attention to the prehospital, emergency department and OR time points as moments when life-threatening exsanguination could be identified and prevented [25]. They identified significantly increased mortality in patients who presented without spontaneous ventilation in the setting of blunt trauma who needed a resuscitative thoracotomy [25]. This is keeping with work by Velmahos, who through stepwise multiple regression analysis identified three independent variables associated with mortality: the need for aortic clamping, intraoperative use of inotropes, and intraoperative time with a systolic blood pressure of 90 mm Hg or less [14]. Asensio's work also demonstrated that patients who survived to die in the OR had more PRBCs transfused in the emergency department prior to being taken to the OR. Mortality in or after the OR was associated with the need for transfusion of more than 16 units of PRBCs or more than 12 mL blood products/min intraoperatively [25]. While both of these studies examined patients who were managed at the early part of the damage control movement in Trauma Surgery, the shift from crystalloid based resuscitation was well underway, and massive transfusion practices were more than just large quantities of PRBCs; plasma and platelet ratios remained fairly consistent at around 1:1:4.

Novel metrics have also been investigated for the guidance of massive resuscitations. Moore and colleagues evaluated the use of tissue oxygen saturation (StO2) in the critically ill trauma population in an effort to quickly identify patients who would decompensate and require initiation of massive transfusion and other interventions. While measurements at 1, 2, and 3 h post-arrival did correlate with long term outcomes such as multiorgan system failure or death, this metric did not perform well enough to be used as a marker for cessation of an activated MTP or as a pre-activation indicator of failure, nor was it studied for this purpose [7].

Barbosa and colleagues in 2011 looked at the data collected for the Trauma Outcomes Group, which was designed to study massive transfusion across 23 participating trauma centers. They found that significantly deranged initial values of

pH, Glasgow Coma Scale (GCS), and HR had the most impact on 24-h mortality, but ultimately concluded that they modestly predicted mortality at best, and alone could not be used to justify stopping MT. [26] Exclusion of patients who died within 30 min for reasons of uncertain plasma or platelet availability in the mortality analysis limits the predictive analysis of these conclusions, since these patients can trigger an MT activation and meet some of the more dynamic definitions of MT despite not achieving a classic massive transfusion definition. In fact, these are often the patients for whom we are left struggling with the question of should an MT have been started or continued. Additional work with the same dataset was unable to identify any clear delineating laboratory values that consistently predicted >90% mortality in patients who received more than 10 units of packed red blood cells, other than noting that patients aged 65 or older with severe head trauma (AIS 5 or 6) had 100% mortality [26]. They did document transfused blood products over the first 24 h from 10 to 140 units of packed red blood cells (PRBCs), finding again one patient who survived after receiving 104 units of PRBCs in the first 24 h [27].

Finally, an exploration of newer criteria of massive hemorrhage, the critical administrative threshold (CAT: 3 units of PRBCs in 1 h), has demonstrated improved sensitivity for 24 h mortality relative to massive transfusion [28]. This is unsurprising, as it is a more granular metric over a tighter time frame than the traditional massive transfusion definition; however, low specificity makes its application limited.

Markers of Futility in Unique Populations

Geriatric

While trauma may not be the most common cause of death in the elderly patient, compared to younger patients they have a significantly higher rate of mortality in the setting of massive transfusion. Nirula et al. used retrospective data from National Trauma Databank and looked specifically at type of injuries or physiologic parameters that predicted futility. In the cohort with severe abdominal or chest trauma, age group 65–74, the presence of severe head injury or profound shock (base deficit <= −12) had <5% chance of survival [13]. In age group 75–84, moderate head injury and moderate shock (base deficit <= −6) had greater than 95% probability of death. In age group > = 85 years old, those with profound shock or those with moderate shock and moderate head injury had less than 5% survival [13]. These categories of injury are highly likely to receive massive transfusion for support and correctly of abnormal physiology; this data would suggest that despite all available resources, as older patients are less able to compensate physiologically for severe trauma, they have a significant rate of mortality. However, no single objective cutoff was identified by this paper that could definitively point to the futility of aggressive care [13]. The authors were clear that any discussion of futility should include a patient's preinjury level of function and quality of life postinjury. Subsequent work by Duvall analyzing trauma in the elderly found that injury severity and comorbidities alone

did not predict mortality, and these alone should not be used to guide the decision of withdrawing care [29]. While this study did not look exclusively consider the withdrawal of MTP, and it provides more insight that the factors that guide decision-making in the critically ill elderly patient must all be considered as a whole and not a separate data points in isolation [29].

Morris's review of mortality in MT using Trauma Quality Improvement Program (TQIP) database confirmed a linear relationship between age and mortality. For patients aged 18–29, in-hospital mortality of those being transfused ten units pRBC in first 4 h was 26.3%, while for individuals aged >80 that mortality was 79.2% [21]. However, they were reluctant to set an objective limit on the number of RBC units that should be transfused in an MT based on age alone, as survivors were found above this threshold.

To aid in this difficult decision-making process, several authors sought to create prognostic tools specifically for the prediction of mortality in the elderly patient after trauma. The goal of these tools being to provide the best possible care for the patient and prevent unnecessary or prolonged suffering. One such example is the Geriatric Trauma Outcome Score, described by Zhao et al., which predicted mortality in the geriatric trauma patient based on age, injury severity scale and a binary score for blood transfusion [30]. Based on these inputs, a score was generated, which correlated with the likelihood of mortality. This score did not take into the total number of RBC units transfused and thus was limited in the application to MT and withdrawal of care [30]. Wu et al. took the Geriatric Trauma Outcome Score one step further and modified it to factor in the number of RBC units transfused to increase its utility in severe trauma, particularly when MTP is required. This analysis found that in the elderly population, transfusion of ten or more units of RBC in first 24 h conferred a four-fold increased risk of mortality compared to those receiving less than ten units of RBC [31].

Pediatric

No data was available for assessing futility in massive transfusion in pediatric trauma patients.

Resource Constrained Environments

Resource limited environments have to define massive transfusion differently than classic trauma MT literature. Riviello and colleagues looked at massive transfusion in Kenya as defined as five or more units of whole blood within 48 h [32]. With yearly shortfalls of blood units manifesting in developing countries, understanding futility takes on additional urgency. However, they were unable to identify a transfused unit value that was significantly related to in-hospital survival, instead of identifying low blood pressure, presence of known comorbidities, or transfusion indication other than trauma or obstetrics as the best predictors of mortality [32]. An

earlier study in Australia using the same definition again demonstrated increased transfusion volumes were associated with mortality without identifying a clear quantity tied to futility [33].

Recommendations Based on the Data

No studies to date have been able to define an objective cutoff, which is not surprising in the face of data that surgeons themselves cannot always identify patients who need MT initiated [34]. The literature has demonstrated that there is no single objective lab value or physiologic parameter that can solely predict the futility of care. This is further compounded by the fact that no two trauma centers are alike, with variable access to resources. It is worth noting that many studies have focused on identifying patients who will benefit from early initiation of MT and extrapolate backward to futility. At best, futility in MT data confirms what many already know, namely that the geriatric population is at much higher risk of mortality in trauma requiring massive resuscitation, consideration should be given to withholding massive transfusion for patients older than 65 years with severe head injuries, but the severity of injury or presence of comorbidities alone should not necessarily deter the use of MT.

Summary of Recommendations

- There is no single objective lab value or physiologic parameter that can be solely referenced to predict futility of care while prolonging MTP (evidence quality moderate; weak recommendation).
- The geriatric population is at a much higher risk of mortality in trauma requiring massive resuscitation, and consideration should be given to withholding massive transfusion for patients older than 65 years with severe head injuries (evidence quality moderate; moderate recommendation).
- No data was available for assessing futility in massive transfusion in pediatric trauma patients (evidence quality very low; no recommendation).

A Personal View of the Data

Ultimately, deciding when to stop MT is going to require a sound, individualized clinical judgment and a team approach that takes into consideration the many variables the trauma patient presents with during an ongoing resuscitation (i.e., age, presenting GCS, comorbid conditions, baseline functional status (if known), survivability of associated injuries, and early family involvement when possible). It is worth considering that the duration of survival, or conversely time to death, is not clearly specified outside of static time points in these trials, and that while the value of an extra day to a family attempting to see their loved one

before they die is incalculable, failure of a patient to respond to maximal therapy should prompt a reevaluation of goals of care.

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5 Is it Time for REBOA to be Considered as an Equivalent to Resuscitative Thoracotomy?

Tanya Anand, Samer Asmar, and Bellal Joseph

Introduction

According to estimates, hemorrhage is responsible for 40% of civilian trauma-related deaths and greater than 90% of military deaths from potentially survivable injuries [1]. While mortality from compressible hemorrhage can be temporized in the field with rapid hemostasis from direct pressure, non-compressible torso hemorrhage (NCTH) remains lethal and requires timely access to an operating room (OR) for definitive hemostasis, equipment, and blood bank resources [2, 3]. To prevent immediate exsanguination before achieving definitive hemorrhage control, aortic cross-clamping remains the primary method for hemorrhage control in these settings [4]. This is typically achieved with an American College y (RT), descending aortic clamping, coupled with emergency surgery to control hemorrhage. [5] The feasibility of RT was first demonstrated in 1976 by Dr. Anna Ledgerwood in a landmark study evaluating the role of thoracic aortic occlusion for massive hemoperitoneum. This study demonstrated that aortic cross-clamping before an exploratory laparotomy in patients in extremis experienced improvement of vital signs, perfusion to the brain and myocardium, and prevented sudden cardiac arrest as the abdominal wall tamponade was released [6]. Despite the morbidity associated with a thoracotomy, selective use in hemorrhaging trauma patients is driven by organized and evidence-based algorithms [7].

The use of resuscitative endovascular occlusion of the aorta (REBOA) was first described in 1954 by Colonel Hughes to address the challenges of traumatic hemorrhage under austere conditions [8]. He utilized aortic balloon occlusion in two

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patients during the Korean War to non-invasively gain control of intra-abdominal hemorrhage. This was one of the first documented instances for aortic balloon occlusion to stem hemorrhage. Though both patients died, he was able to improve central perfusion in one patient temporarily [8].

The past decade witnessed an evolution in resuscitation paradigms with the greater extracorporeal capability and the introduction of more precise and selective technology. As endovascular techniques improved, so did interest in REBOA. Case reports demonstrated effectiveness in patients with hemorrhagic shock from ruptured abdominal aortic aneurysms, aortic-enteric fistulas, postpartum, or abdominal/pelvic surgery hemorrhage, hemoperitoneum after splenic artery aneurysm, gastrointestinal hemorrhage, and vascular injuries [9–12]. Despite emerging indications and greater potential as an additional tool for improving resuscitation, the true efficacy of REBOA as a bridging hemostatic measure in civilian injury patterns is not yet established, and the hemostatic effect may not be as profound as previously theorized [13]. Although the use of REBOA to temporize hemorrhage has increased in civilian trauma care over the past fifteen years, there is no high-grade empirical evidence demonstrating improvement in survival when REBOA is utilized in comparison to the standard of care for severe hemorrhage [14, 15]. The risk-benefit ratio of this technology is still being investigated in different patient populations. Before widespread adoption, a rational and evidence-based evaluation of this tool is needed to identify its correct indications.

Search Strategy

PUBMED and Google Scholar (first ten pages) were searched using the terms REBOA and resuscitative thoracotomy (RT). All resulting citations were screened for relevance. Two reviewers (SA and TA) performed an iterative process starting with titles, then abstracts and full text as necessary for inclusion or exclusion. The research team excluded references including only pediatric patients, patients without blood loss, those that described occlusion of vessels other than the aorta, reviews, letters to the editor, opinion pieces and those without primary data. Articles that controlled aortic flow using extravascular methods like clamps and extracorporeal circuits were also included. Reviews were screened for relevant citations, and those with REBOA and/or RT patients or groups were included in this chapter. Disagreements about study eligibility were discussed, and the consensus was reached regarding inclusion. Once studies for inclusion were identified, the full text was reviewed, and key data extracted. For animal studies, data included comparator groups, hemorrhage protocol, duration of occlusion, devices used, comorbidities, and primary study aims. For clinical studies and case reports, data included patient type and number, device used, comparator group, major findings, and method of achieving aortic occlusion.

PICO

Patients	Intervention	Comparator	Outcomes
Exsanguinating trauma patients	REBOA	Resuscitative thoracotomy (RT)	Complications, morbidity, and mortality

Procedural Complexity: Who Can Perform What?

Only surgeons with experience in the management of cardiac and thoracic injuries should perform RT (e.g., trauma, cardiothoracic, vascular surgeons) [16]. In the civilian setting, the American College of Surgeons—Committee on Trauma (ACS-COT) and the American College of Emergency Physicians (ACEP) emphasized that REBOA should be performed by an acute care surgeon or an interventionalist (vascular surgeon or interventional radiologist) trained in REBOA, with the implication that this individual has the capabilities to surgically intervene. Emergency medicine (EM) physicians with added certification in critical care (EMCC) trained in REBOA may train and perform REBOA in conjunction with an acute care surgeon or vascular surgeon trained in REBOA, as long as the surgeon(s) is/are immediately available to control the focused source of bleeding definitively [13]. EMCC-certified physicians, especially those with no critical care training, must not perform REBOA unless a surgeon is immediately available [13].

RT used in the military setting is restricted to forward military treatment facilities with surgical and resuscitation capability (typically Role-2 or higher) and by surgeons familiar with and trained in this procedure [17]. REBOA use in the military setting is considered an exceptional circumstance in which it may be used, as long as those deploying the device have formal training in Basic Endovascular Skills for Trauma (BEST course®). Femoral access in this hemodynamically unstable patient population is difficult and is the rate-limiting step in placing a REBOA. If placement is unsuccessful, then the individual must have the skills to perform an open femoral cutdown. Besides, once access is achieved, monitoring the patient for complications associated with access or balloon inflation is important. Thus training for this device must be comprehensive and multifaceted; The BEST course® achieves these goals [18].

The Ideal Setting: Where and When Should the Intervention Occur?

The Western Trauma Association published its guidelines for RT in 2012. Their recommendation for undergoing ED RT is based on the type of trauma (blunt vs. penetrating), pre-hospital transport time with ongoing CPR, and signs of life. Patients with penetrating trauma with absent signs of life and transport time with ongoing CPR exceeding 15 min are pronounced dead. Patients presenting with

blunt trauma with pre-hospital CPR exceeding 10 min and no signs of life are pronounced dead. All other blunt or penetrating trauma patients in extremis, who are not pronounced dead as per the aforementioned criteria, should undergo ED RT. [7] The Eastern Association for the Surgery of Trauma (EAST) guidelines conditionally recommend against ED RT in patients with cardiac arrest in blunt trauma patients and no signs of life on arrival. These guidelines are based on a meta-analysis of 72 studies including 10,238 patients. All patients with penetrating thoracic or extra-thoracic injuries, regardless of signs of life, should undergo ED RT; While only patients with blunt trauma and signs of life should undergo ED RT. [19] Patients deemed salvageable after ED RT should be transported to the OR for further management [20].

Some EMS teams outside of the USA, using REBOA are staffed with physician providers and are equipped to perform RT in this setting [21]. However, any attempt to transfer patients with an aortic clamp is predestined to fail [22]. In the USA, this is not the case; thus the recommendation remains to resuscitate and transport the patient to a nearby trauma center, as quickly as possible [18]. The ACS-COT's joint statement addressed the use of REBOA in the pre-hospital environment [15, 18]. They indicate an allowance for REBOA placement in the specific instance that a physician with REBOA experience is placing it, and that definitive control is within 15 and 30 min, for balloons inflated in Zone I and III, respectively [18].

The consensus among experts is that REBOA can be used in austere military settings, EDs, ORs, and intensive care units, but disagrees with the statement that REBOA is feasible in the pre-hospital setting [23]. The rationale is that one must also consider the experience and training of the providers performing this procedure in this setting. Outside of the USA, much of the literature regarding REBOA in the pre-hospital setting is with physician providers as part of the EMS team.

The UK-REBOA trial, which explores this question, began enrollment in 2017 and is set to publish its findings in March 2021. However, this trial's enrollment process is proving to be prolonged, which may delay its ability to provide a definitive answer anytime soon. In light of the current evidence, the issue of pre-hospital insertion of REBOA should be approached with caution. Although the UK experience is encouraging with reported improved survival, the modality and results are not easily reproducible [24]. More research must be performed before a positive recommendation can be made for this procedure in the pre-hospital setting. Until these studies are performed, REBOA should be reserved for select cases in advanced centers with high expertise and a clear post-insertion protocol.

Hemorrhage Control in Austere Environments

In austere environments, non-compressible torso hemorrhage (NCTH) was found to be the most common cause of potentially survivable deaths for wounded soldiers [25]. The inability to control bleeding from NCTH is addressed in the Tactical Combat Casualty Care Guidelines as well as the 2020 Clinical Practice Guidelines (CPG). [26] NCTH hemorrhage is lethal and can lead to prohibitively high mortality

rates in the first few minutes after injury. The estimated peak time of death or irreversible metabolic derangements after truncal injury may occur well before 30 min and likely before reaching definitive care [26]. Even in the civilian population, patients with gunshot wounds (GSW) or with high torso AIS (Abbreviated Injury Scale) scores had higher mortality rates within the first fifteen minutes [27]. As a field, or on-scene RT is not a meaningful option given the complexity of post-thoracotomy management and disappointing results [28, 29]. REBOA is an attractive tool when combined with whole blood resuscitation, to temporize hemorrhage and extend the "golden hour" or half-hour as one may call it. It can be deployed in an austere environment en route to reaching definitive care [27]. Its role is important to consider given the percentage of patients who die of their wounds in the field, as well as the dearth of additional temporizing techniques in combatants sustaining NCTH.

One arena in which REBOA is potentially useful is in the austere setting. However, the perceived benefit of REBOA in NCTH is present with the caveat that definitive hemorrhage control occurs within 30 min of balloon inflation [30]. Morbidity and mortality from REBOA remain high even within fifteen minutes of balloon inflation, negating the benefits of hemorrhage control; Thus, timely transport must be present [31]. As the catheter technology and occlusion practices continue to evolve, hopefully so will the quality and quantity of data guiding its use [32]. Despite a well-organized and structured trauma system, with improved transport times, hemorrhage control in the setting of NCTH remains a considerable challenge.

In-Hospital Management: When to Inflate or Directly Operate?

As opposed to the comparatively austere pre-hospital setting, the hospital is a backdrop in which definitive control may be achieved via its trauma team and the OR. Potential indications for RT or REBOA in trauma are primarily based on the patient's injury pattern and physiological status at the presentation in the trauma bay. In patients who present without a pulse, the decision to intervene is based on the mechanism and pattern of injury, duration of CPR, presence of a narrow organized complex cardiac rhythm, and/or organized cardiac activity by an ultrasound exam. For trauma patients presenting with signs of life on admission in profound shock, the use of RT vs. REBOA is determined by vital signs, response to resuscitation, the likely pattern of injury, and the source of hemorrhage. All of these parameters are equally important in determining the intervention required [33]. The updated CPG of the Joint Trauma System (JTS) are descriptive in the indications for REBOA use in patients with either traumatic cardiac arrest or profound shock and acknowledge the limitations and danger of this technology as well [30]. This section will guide the use of REBOA vs. RT in trauma. The indications presented henceforth are derived from the JTS CPG. [34] Modified algorithms, derived from expert opinions regarding intervention with REBOA or RT, for the management of traumatic arrest and the management of hemorrhagic trauma with concomitant shock, are depicted in Figs. 5.1 and 5.2.

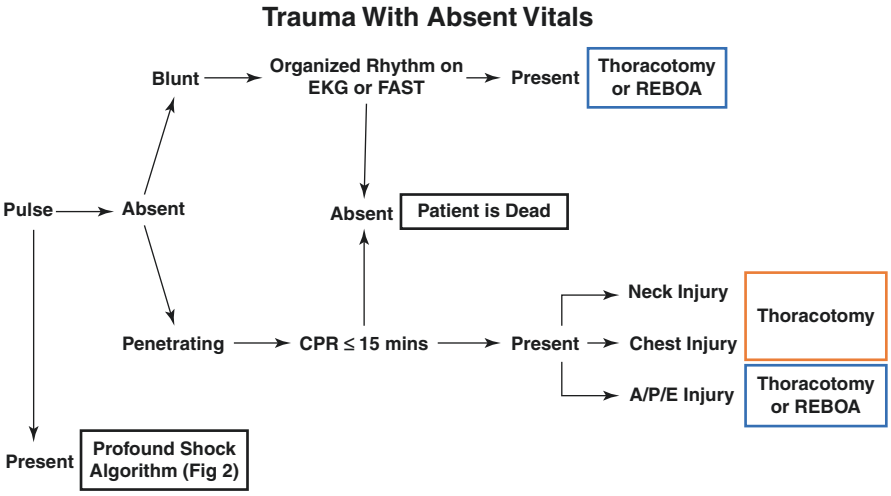

Fig. 5.1 Traumatic arrest algorithm for RT or REBOA for hemorrhagic shock

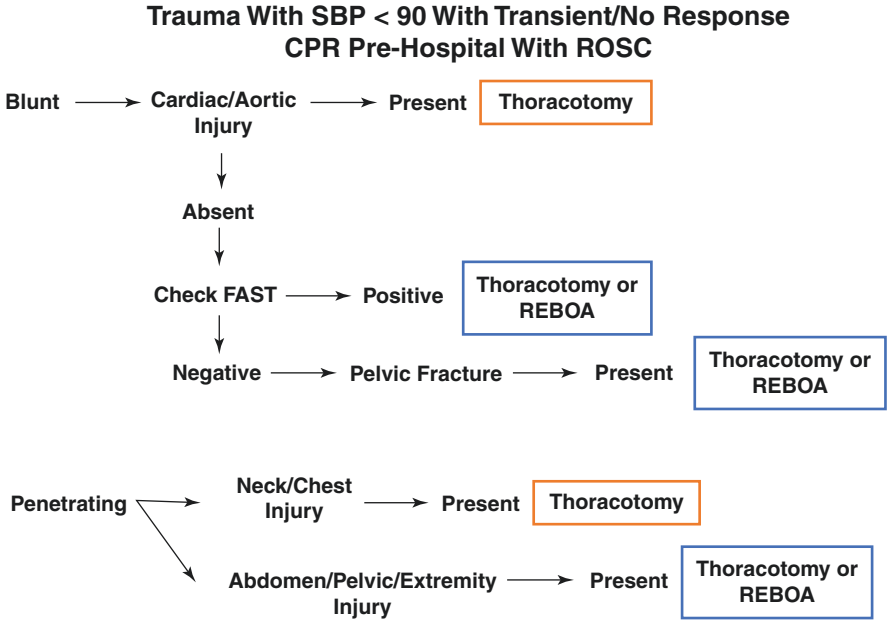

Fig. 5.2 Profound hemorrhagic shock algorithm for RT or REBOA

1. **Operate, Never Inflate:**
   - Patients with penetrating thoracic trauma who present in profound shock should undergo prompt RT. Upon accessing the thoracic cavity, definitive hemorrhage control can be directly performed, and the descending thoracic

aorta can be clamped above the diaphragm to augment myocardial and brain perfusion. The deployment of REBOA in the setting of thoracic hemorrhage is contraindicated given its potential to exacerbate hemorrhage from great vessel injury [35].

- Patients with blunt cardiac injury or traumatic aortic injury who present in profound shock should undergo prompt RT. In this setting, deploying REBOA is contraindicated, and RT remains the standard of care.
- Patients with hemorrhage proximal to zones of REBOA occlusion, including areas of the neck, axilla, and superior mediastinum, should strictly undergo RT if surgical intervention is deemed necessary [7].

2. **Operate or Inflate:**
   - Patients arriving with cardiopulmonary resuscitation (CPR) in progress should strictly undergo RT given that the patient is in extremis [36]. However, some emerging reports highlight the potential role of REBOA in this population [37].
   - Patients with blunt trauma arriving with loss of vitals, but with organized rhythm detected on an EKG or FAST, with low/no suspicion for supradiaphragmatic trauma, intervention with either zone I REBOA or RT is feasible.
   - Patients with penetrating abdominal, pelvic, or lower extremity trauma receiving CPR for less than 15 min, without a devastating head injury, may also be candidates for either REBOA or RT.
   - Patients with penetrating injuries having a thoracoabdominal trajectory can undergo REBOA, as opposed to RT, only after ascertaining that the source of hemorrhage is sub-diaphragmatic and ruling out thoracic hemorrhage using a chest X-ray and a FAST exam [38].
   - In all these patients, the decision to place a REBOA as opposed to RT is still subject to conjecture and risk and must be performed within minutes of presentation, without contributing to a delay in definitive hemorrhage control.
3. **Do Not Operate or Inflate:**
   - Relative contraindications to both procedures include elderly age (age > 70 years), pulseless cardiac electric activity arrest exceeding 10 min, presence of terminal illness, and/or profound comorbidities [39].

Catch-22: Anatomic Indication Does Not Necessarily Imply Physiologic Indication!

In a recent study, it was reported that 55% of patients with potential anatomic indications for REBOA ultimately did not have physiologic indications once a response to resuscitation was reached [40]. Such information is readily obtained from the patient's primary survey, clinical assessment, and imaging modalities such as focused abdominal sonographic examination for trauma (FAST), chest, and pelvic X-ray. In those patients, REBOA, as opposed to RT, may be inserted for transient responders or non-responders to resuscitation upon verification of the sub-diaphragmatic source of the hemorrhage [41].

In-Hospital Outcomes: What the Evidence Suggests?

- At present, we do not have high-quality Level I evidence for REBOA efficacy in the treatment of traumatic hemorrhagic shock, and additional research is warranted.

Current guidelines or algorithms adopted by trauma centers are not backed by empirical evidence demonstrating a clear survival benefit of REBOA when compared to RT, which is the standard of care.

- Studies ensuring REBOA's safety and demonstrating an acceptable risk-benefit ratio are also lacking. The current indications for REBOA are based on low-quality evidence and expert opinion with little consensus.

A recent systematic review and meta-analysis compared REBOA to RT to determine outcomes in patients with NCTH. The constituent three studies included data from the following databases: Japanese Trauma Data Bank, Japanese Diagnosis Procedure Combination Data Bank, and The American Association for the Surgery of Trauma Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery Registry [42–44]. This meta-analysis, reflecting mainly observational data, concluded that REBOA had a positive effect on mortality among NCTH patients compared to RT. [45] However, these results may have significant indications and survival bias, making the comparison between the two methods difficult in each of these three studies [46, 47]. When REBOA is compared to RT, the patients undergoing an RT are almost uniformly in cardiac arrest and dire straits; thus, the outcome from this comparison tends to favor REBOA and jeopardizes the internal and external validity of the studies [48]. Though difficult, standardization of comparison groups, with randomization is needed to provide more definitive answers.

Complications and Limitations

Despite the comparative morbidity of undergoing a large chest wall incision, experience with REBOA has shown us that this device is not without its own risk. In the past three decades, there has been a significant clinical shift in the performance of RT from a nearly obligatory procedure to a more selective undertaking [7]. Enduring the test of time, the complications and success rates of RT are primarily dependent on the patient selection that relies on injury patterns that dictate where RT is performed (ED vs. OR), that in and by itself may influence patient outcomes [49]. The optimal application of RT requires a thorough understanding of its physiologic goals, technical skills, and subsequent cardiovascular and metabolic derangements. Technical complications of RT involve virtually every intrathoracic structure, predisposing to lacerations of the heart, coronaries, aorta, phrenic nerves, esophagus,

and/or lungs, as well as avulsion of aortic branches to components of the mediastinum. In those who survive RT, recurrent chest bleeding, pericarditis, pleuritis, and infections to the sternum and chest wall may occur, and post-pericardiotomy syndrome [50]. The complications associated with the use of REBOA are partially attributed to the limitations of currently available devices. These limitations include the size of the catheter and the introducer sheath and catheter stability. Technical complications are divided into several categories: issues associated with arterial access, challenges associated with balloon positioning, inflation, and deflation, as well as with sheath removal [51, 52]. Reported femoral access complications to include arterial disruption, dissection, pseudoaneurysms, hematoma, thromboembolism, extremity ischemia, and the problem of prolonged occlusion time and delayed definitive control. Aortoiliac injuries have also occurred; these include intimal tear, dissection, thrombosis, and rupture, which may be fatal or cause limb loss. Balloon rupture may occur with over-inflation of the balloon relative to the aortic diameter. Unintended inflation of the balloon in the iliac vessels may lead to rupture or thrombosis [51–53].

Other limitations common to open or endovascular occlusion of the aorta include occlusion time and physiology post-release. Even if one's technique is impeccable, prolonged occlusion results in significant distal ischemic reperfusion injury, predisposing the patient to organ dysfunction, cardiovascular collapse, and spinal cord ischemia [51, 54, 55]. In as little as fifteen minutes, the metabolic derangements can be irreversible, thus emphasizing the importance of proximity to definitive hemorrhage control, which is feasible with RT.

Recently, to mitigate the risk associated with occlusion times, partial occlusion or intermittent deflation/inflation of the balloon has been introduced [56]. Partial REBOA (pREBOA) or intermittent occlusion REBOA (iREBOA) practices were utilizing the same catheter to allow limited blood flow past the balloon. Theoretically, allowing some flow may limit complications of ischemic reperfusion injury. Currently, REBOA is primarily utilized as an all-or-none flow occlusive device. Several animal studies indicate this is potentially feasible in limiting ischemic burden; however, partial occlusion is difficult to achieve without continuous monitoring of the blood pressure both above and below the balloon along with a clinical assessment of the rate of bleeding. Besides, determining and maintaining a consistent degree of partial inflation is difficult to achieve, given the complex physiologic environment [56]. Thus at this point, there is presently insufficient data to guide this practice [32, 57–59].

In summary, limitations of REBOA range from technical aspects of placement and maintenance to the metabolic derangements from prolonged ischemia. Even if the catheter or balloon profile evolves such that placement is more facile, the ultimate limitation, whether the patient is undergoing an RT or REBOA placement, is proximity to definitive hemorrhage control. Unlike an RT, which is usually performed in patients in extremis and does not possess the same technical limitations, REBOA placement in a hypotensive patient nearing extremis may result in a prolonged time to achieving this control because of the above-noted limitations.

Table 5.1 Summary of RT vs. REBOA

Variables	RT	REBOA
Procedural Complexity	High	Low
Personnel	Surgeon Only	Surgeon/Interventionalist/EM+Critical Care Certification
Location	ED/OR	Prehospital + Inhospital
Temporizing Hemorrhage Ability	Complete Occlusion	Complete Occlusion
Definitive Hemorrhage Control	Yes	No
Indications	More + Better Evidence	Few + Lower Evidence
In-Hospital Outcomes	Standardized Studies With Randomization Are Needed For A Definitive Answer	
Complications & Limitations	Low	High
Overall Verdict	Currently, RT Takes Precedence Over REBOA	

Recommendations Based on the Data

- In its current state and indications, it is not time for REBOA to replace RT in patients with severe NCTH (Table 5.1).

The indications for RT are derived from evidence-based algorithms that establish the feasibility of intervention based on clear inclusion and exclusion criteria. RT has endured the test of time, subjecting it to decades of procedural and patient selection refinement. RT is not without its complications, but physicians have had ample time to learn from these complications, further contributing to an improvement in post-operative management. On the other hand, REBOA is novel. The catheter continues to evolve, and balloon sizes are not final, device application (pREBOA vs. iREBOA vs. complete occlusion) is still under investigation. The ease of safely performing this procedure is a concern as well. Even the complications associated with this device have not been adequately recognized. REBOA's utilization currently surpasses its indications and requires certification before use [60]. Its utilization must be adapted to the individual institution's available resources, and logistical familiarity is needed, as is greater practice with this procedure [61]. Besides, just like RT, there needs to be a well-defined population delineated before providing any strong recommendations for its use. This, too, will require time, and controlled prospective studies.

Summary of Recommendations

- In its current state and indications, it is not time for REBOA to replace RT in patients with severe NCTH (evidence quality high; strong recommendation).

- Its utilization must be adapted to the individual institution's available resources, and logistical familiarity is needed, as is greater practice with this procedure (evidence quality low; moderate recommendation).

Personal View of the Data

However, there might be a future for REBOA, but it is with a specific patient population and a specific set of indications that will allow this procedure to succeed. While there are several animal models and cadaver studies in the literature, these results have yet to be translated into the hemorrhaging trauma patient. The goal of this research is to ultimately make this technique user-friendly, efficient, and safe for the hemorrhaging patient [62, 63]. With more level I and level II evidence, standardization of technique, and widespread availability, we can eventually outline recommendations to make this group of patients less vulnerable to injury. Moving forward, increased efforts should focus on integrating REBOA to RT instead of attempting to replace it.

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Part II

Wound Management

6 In Patients with Traumatic Extremity Wounds Is Negative Pressure Wound Therapy Superior as Compared to Standard Dressing Changes?

Brett M. Tracy, Deepika Koganti, and Christopher J. Dente

Introduction

The global negative pressure wound therapy (NPWT) market size is expected to reach 2.74 billion dollars by 2026, displaying a compound annual growth rate of 5.1% during that time [1]. This economic surge in NPWT is paralleled in the clinical and academic world with more than 400 manuscripts in circulation on this wound care therapy [2]. Since its approval by the Food and Drug Administration (FDA) in 1997, NPWT has progressively gained acceptance as an option for treatment of traumatic superficial and deep soft tissue defects, open extremity fractures, and damage control laparotomy wounds [3]. From a physiologic standpoint, it is believed to create a moist environment, augment blood flow, stimulate cell proliferation, aid in thermoregulation, and induce angiogenesis through microdeformation [4, 5]. In turn, NPWT should theoretically augment wound healing, promote tissue coverage of exposed bone or hardware, minimize hematoma formation, and potentially decrease the complexity of future reconstructive surgery. Interestingly, multiple meta-analyses suggest that the evidence supporting NPWT is low quality and stems from poorly designed studies [2, 5, 6]. Therefore, the aim of this chapter is to determine if patients with traumatic extremity wounds benefit from NPWT as compared to standard dressings regarding wound outcomes, hospital length of stay, infectious sequelae, and quality of life outcomes (Table 6.1).

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Table 6.1 Description of research strategy using PICO format

Criteria	Determinants
Population	Patients with traumatic extremity wounds
Intervention	Negative pressure wound therapy
Comparison	Traditional wound dressings (i.e., moist-to-dry gauze)
Outcome(s)	Wound healing; hospital length of stay; infectious complications; quality of life

Search Strategy

The literature evaluation was performed by searching PubMed, Google Scholar, Science Direct, and OVID databases for the following terms: "negative pressure wound therapy," "NPWT," "vacuum-assisted wound closure," or "VAC" in conjunction with "trauma" or "traumatic." Searches were limited to studies published after 1997 (the year the FDA approved the clinical use of NPWT), manuscripts written in English, and studies that specifically evaluated NPWT in traumatic extremity wounds. Titles and abstracts of resultant studies were reviewed for relevance; if the abstract did not yield sufficient information, the full article was examined for suitability. Additionally, if a selected publication included pertinent data from a previous study, that original study was also retrieved and analyzed for inclusion. All studies meeting the above criteria were then fully reviewed by the authors.

Results

The Advent of Negative Pressure Wound Therapy

In 1997, Müllner et al. published a 3-year prospective evaluation of 45 patients who had sustained traumatic lower extremity soft tissue defects. After bony stabilization, wound debridement, and application of a NPWT device, 84% of patients demonstrated a reduction in wound dimensions. The authors asserted that this shrinkage was afforded by NPWT and would ultimately hasten healing times and curtail infections [7]. In the same year, Argenta and Morykwas published their experience with a NPWT device created by Kinetics Concept, Inc. (KCI®) called a vacuum-assisted wound closure (V.A.C.) device. They observed the fastest granulation in the 31 acute traumatic wounds in comparison to patients with pressure ulcers, venous stasis ulcers, and subacute lesions [8]. The authors attributed this augmented healing to the device's ability to remove interstitial fluid, increase tissue vascularity, and decrease bacterial colonization [8]. Although these two series are hampered by a lack of randomization, a clearly defined exclusion criteria, and external validation, they still introduced a therapy that could promote a wound bed amenable to downstream closure techniques [8].

Over the next several years, multiple experiences with NPWT were published. In 2001, DeFranzo et al. shared a series of 49 traumatic lower extremity wounds

managed with the V.A.C. device. The authors noted less tissue edema, faster granulation tissue coverage over bone and hardware, and less wound surface area when using NPWT [9]. Two years later, Herscovici and associates published a 21-patient series of high-energy soft tissue injuries treated with V.A.C. therapy. They suggested that V.A.C. therapy does not replace the need for débridement of necrotic tissue but is a viable clinical tool for traumatic injuries that can be safely performed at bedside (~75% of sponge changes) [10]. Although descriptive in nature and limited by lack of control groups, these studies proved instrumental for supporting wound care during Operation Iraqi Freedom. Within a year of the war's inception, NPWT was approved as an adjunct to wound care and documented in the US Department of Defense's Handbook of Emergency War Surgery (2004) [11].

After many grueling months of changing wet-to-moist dressings twice daily for traumatic combat-related injuries, field and hospital personnel began to utilize NPWT given the longer period of time in between sponge changes [12]. Within a 6-month period, NPWT for extremity wounds increased from 46% to more than 90%. However, NPWT was not immediately used during combat transport due to flight team inexperience with equipment and potential environmental issues. Nevertheless, in July 2006, KCI's V.A.C. Freedom device was approved for aeromedical transport use by the Air Mobility Command US Air Force given its unwavering performance in high altitudes, temperature extremes, and during rapid decompression [12]. Fang et al. prospectively observed 30 patients with combat-related wounds in 2008 who were treated with this V.A.C. Freedom device. All patients in their cohort had a V.A.C. placed at a ground facility and were then flown to a destination; all individuals arrived with a functional system having sustained no in-flight complications. Fang et al. believed NPWT could safely and feasibly be expanded to aeromedical evacuation [13].

Impact on Wound Healing

NPWT rapidly infiltrated the armamentarium of the trauma surgeon regardless of evidence substantiating its efficacy [3, 5, 14, 15]. This phenomenon occurred likely because NPWT is easily learned, appealing to patients, and applicable to a large number of scenarios [16]. Not surprisingly, from 2001 to 2007, Medicare payments for NPWT and associated equipment increased almost 600% from 24 million to 164 million dollars [17]. One of the original theorized benefits of NPWT was that it decreased the need for complex flap coverage in lower extremity fractures with soft tissue defects [15, 18]. For example, Dedmond and colleagues evaluated the role of NPWT on wound closure in adults with type III open tibial shaft fractures. In this 2006 retrospective review of 50 patients treated with NPWT after bony fixation, 24 (48%) patients had fractures that historically would have required a rotational flap or free tissue transfer. However, only 14 (28%) patients required these specific operative interventions while the remaining 10 (20%) were able to undergo delayed primary closure, split-thickness skin grafting, or routine epithelialization presumably because of NPWT [19].

In a smaller series, the same authors examined 15 children with open type III tibial shaft treated with NPWT. They again found a 50% reduction in the need for free tissue transfers and rotational muscle flaps for wound coverage in patients treated with NPWT compared to historical controls [20]. Liu and associates retrospectively reviewed 103 patients with lower extremity trauma over an 8-year period. Prior to a planned free flap coverage, NPWT was used in 78 patients and moist gauze was used in 25 patients [21]. Patients treated with NPWT had significantly lower rates of flap take-back and flap thrombosis; however, the NPWT group received significantly more wound debridements prior to flap coverage. The authors proposed that NPWT aids in wound coverage in patients destined for flap surgery but does not prevent postoperative complications [21].

Some of the first prospective randomized trials examining NPWT were performed by Stannard et al. in 2006 [22]. Their first study enrolled 44 patients with traumatic injuries who required surgical intervention and who demonstrated postoperative drainage for at least 5 days after surgery. In this "draining hematoma" cohorts, 31 patients received standard treatment and 13 patients received NPWT. The standard therapy drained for an additional 3.1 days while the NPWT drained for only 1.6 days longer ($p = 0.03$). The second study enrolled 44 patients who had undergone surgical repair of calcaneal, pilon, or tibial plateau fractures. Twenty-four patients had a regular dressing placed atop their surgical incision and 20 patients had NPWT applied to their incision. Drainage occurred for 4.8 days in the standard dressing group but only for 1.8 days in the NPWT group ($p = 0.02$) [22]. The authors concluded that wounds heal faster (based on wound drainage) using NPWT. Unlike many previous studies, these authors recognized that their investigation was limited by its small sample size [22, 23].

More recently in 2018, Älgå et al. published the results of a pragmatic, randomized controlled superiority trial performed at two civilian medical centers in Jordan and Iraq [24]. During this 3-year study, 174 patients were enrolled after sustaining a conflict-related extremity wound no more than 72 h prior to presentation. In comparison to standard gauze dressings, NPWT offered no significant benefit in rates of wound closure, limb amputation, sepsis, or bleeding [24]. The authors questioned how NPWT technology became introduced, particularly in resource-limited conflict settings, without scientific support for its efficacy [24–26]. Results from this rigorous study support our recommendation on NPWT and wound healing (Table 6.2).

Table 6.2 NPWT and wound healing recommendation

Statement	Level of evidence
NPWT does not improve wound healing, timing of closure, nor need for flap coverage compared to conventional dressings.	A

Effect on Hospital Length of Stay

Potentially as an extrapolation of the results from the tissue flap literature, many surgeons began to speculate that NPWT could offer shorter inpatient hospitalizations. Shilt et al. retrospectively examined 31 children with soft tissue wounds from lawnmower injuries; 16 received V.A.C. therapy and 15 were treated with traditional dressings [27]. While there was a trend toward fewer revision amputations and an improvement in function following treatment, they did not identify a shorter length of stay. In fact, children receiving NPWT had a mean length of stay of 16.8 days compared to a 10.2-day hospitalization in the traditional treatment group ($p = 0.04$). The authors argue that, at the time of their study, V.A.C. therapy was not yet approved for home use, thus necessitating hospitalization [27]. Arti et al. prospectively randomized 90 patients in Iran with open fracture wounds to NPWT or conventional wound dressings. The NPWT group exhibited an average 1.5-day shorter hospital length of stay (9.7 vs 11.2 days, $p = 0.01$) compared to the conventional dressing group [28]. This study's results are encouraging because of its prospective randomization; however, the authors do not account for important confounding variables such as patient comorbidity, initial wound severity, or concomitant injury profile.

Kaplan and colleagues also examined the impact of NPWT on hospital length of stay in their 2009 retrospective review [29]. They specifically compared wounds that were treated early ($\leq$2 days of admission; $n = 518$) and wounds treated late ($\geq$ 3 days, $n = 1000$). The early group had significantly shorter inpatient hospitalizations (10.4 vs 20.6 days; $p < 0.0001$), shorter intensive care unit stays (5.3 vs 12.4 days; $p < 0.0001$), and shorter duration of NPWT (5.1 vs 6.0 days; $p = 0.049$). Although this study was well-powered, the inclusion criteria were very broad [29]. They enrolled patients with upper or lower extremity trauma, acute abdominal trauma, cardiovascular-related trauma or surgical wounds, or if they had undergone a sternotomy, fasciotomy, or flap or graft procedure [29]. Furthermore, they did not compare NPWT to standard dressings but rather analyzed the timing of NPWT initiation. Because of the flawed methodology utilized and limitations discussed, we cannot definitively state that NPWT use leads to a decreased hospital length of stay (Table 6.3).

Table 6.3 NPWT and hospital length of stay recommendation

Statement	Level of evidence
Use of NPWT may be associated with a decreased inpatient hospital length of stay; however, this recommendation does not account for inpatient days spent awaiting outpatient therapy approval by an insurance company.	B

Influence on Infectious Complications

A large portion of NPWT research seeks to identify a reduction in infectious complications through the use of this wound therapy. Rezzadeh and associates retrospectively reviewed 32 patients with type III open tibial fractures [30]. The patients were divided into three groups based on time elapsed between injury and definitive reconstruction: acute ($\leq$ 6 days; $n = 8$), subacute ($\geq$ 7 days to <42 days; $n = 16$), and chronic ($\geq$ 42 days; $n = 8$). Each time category was then divided into patients receiving NPWT and traditional wet-to-dry gauze dressings. They noted lower rates of surgical site infections in the NPWT acute group ($p = 0.007$), lower rates of osteomyelitis in the NPWT subacute group ($p = 0.02$), and lower rates of osteomyelitis ($p = 0.04$) and nonunion ($p = 0.002$) in the NPWT chronic group [30]. The authors argue that NPWT in patients with open lower extremity fractures reduces complications associated with limb salvage surgery and serves as a temporizing measure before flap surgery. These sweeping conclusions are substantially limited by the overall study sample size, which were often rendered after comparing two patients with NPWT to six patients with wet-to-dry gauze (i.e., acute group).

In another investigation by Stannard et al., 58 patients with severe lower extremity open fractures were prospectively randomized to NPWT ($n = 35$) or standard wound therapy ($n = 23$) following initial wound irrigation and debridement [31]. The authors concluded that NPWT reduces overall infection rates because only two patients (9%) treated with NPWT developed infections compared to seven patients (20%) in the control group. However, the authors cautioned that there was no significant difference between infection rates when complications were stratified by timing (acute or late) [31]. They also failed to strictly define what constituted an infection in their study.

In a similarly designed investigation set in India, Virani et al. prospectively evaluated 93 patients with open tibial fractures who were randomized to NPWT ($n = 43$) or standard dressings ($n = 50$). They found a significantly lower percentage of overall infections (acute infections and osteomyelitis) in the NPWT group compared to the control group (4.6% vs 22%, $p < 0.05$). The authors stated that NPWT is beneficial in preventing acute infections and osteomyelitis in open fractures, yet they fail to address that there was no difference among individual rates of acute infection and rates of osteomyelitis between groups. Furthermore, the authors briefly mention that some patients in the analysis presented more than 48 h after injury and had not received antibiotics during that time. They also disclose that, of the 11 patients developing osteomyelitis, seven were smokers and three were diabetics but do not specify to which treatment group they belonged. Additionally, they excluded wounds that dehisced after primary closure and did not explain the antibiotic protocol for their study [32]. These limitations considerably lower this study's level of evidence.

In 2019, Hahn and associates prospectively randomized 65 patients with open, contaminated lower extremity wounds from trauma to conventional NPWT or silver

Table 6.4 NPWT and infectious complications recommendation

Statement	Level of evidence
Infectious wound complications are no different between NPWT and conventional dressings. The addition of silver to NPWT may decrease bacterial counts of *S. aureus* species.	B

impregnated NPWT [33]. The authors obtained serial bacterial cultures from wounds over 4 weeks from the wounds and detected a significant reduction in Methicillin-resistant *Staphylococcus aureus* (MRSA) colonization in the silver impregnated NPWT wounds. These findings correlated with previous animal research performed by Stinner et al. in 2011 [34]. Complex extremity wounds in goats were inoculated with *Pseudomonas aeruginosa* or *Staphylococcus aureus*, debrided 6 h after inoculation, and treated with silver impregnated gauze combined with NPWT. After 6 days, the wounds inoculated with *P. aeruginosa* had similar bacterial counts between the treatment and control group. For wounds with *S. aureus*, the bacterial count in the wounds treated with NPWT and silver contained much less bacteria than the regular NPWT (25% and 115%, $p = 0.001$) [34]. While the addition of silver to NPWT appears to effectively reduce bacterial counts in contaminated wounds, overall infectious complications are not significantly improved with this treatment modality (Table 6.4).

Role in Quality of Life

Recently, NPWT has been examined with respect to patient-centered outcomes like quality of life, disability, and pain. In 2018, Costa and colleagues published the results of a United Kingdom Major Trauma Network multicenter, randomized trial comparing NPWT to standard wound care at 24 different centers [25]. Among 460 patients with a severe, open fracture of the lower limb, 88% completed the trial. Analysis demonstrated no significant difference in the quality of life or disability scores between the treatments [25]. Nearly identical results were reached by Ondieki et al. who compared NPWT to routine gauze dressings in patients with acute traumatic wounds. They found no significant difference in subjective pain scores during dressing changes as well as no difference in time to full wound granulation, reduction in wound surface area, or infection rates [35].

Costa et al. performed another multicenter randomized trial including 1548 patients who underwent surgery for a traumatic lower limb fracture [26]. They compared incisional NPWT to traditional wound dressings and demonstrated no difference between groups regarding disability scores, health-related quality of life, surgical scarring, or chronic pain at 3- and 6-months [26]. The amalgam of these contemporary, well-powered scientific studies provides considerable evidence that NPWT is not superior to traditional wound care for traumatic open extremity fractures (Table 6.5).

Table 6.5 NPWT and quality of life recommendation

Statement	Level of evidence
NPWT does not offer an improvement in quality of life compared to conventional dressings.	A

Recommendations Based on the Data

A recent Cochrane systematic review based on the available scientific literature determined that NPWT does not lead to superior wound healing rates in traumatic open fractures compared to standard therapy. The review further notes insufficient evidence to determine the impact of NPWT on infection, wound closure, quality of life, and pain in open fractures [36]. Despite these findings, NPWT paradoxically remains lauded for increasing limb salvage and function as well as promoting faster wound closure than conventional dressings [11, 37, 38]. Indeed, NPWT may be another instance where enthusiasm for an innovative technology outshines scientific evidence and providers do not remember the adage, "new is not always better."

Summary of Recommendations

- NPWT does not improve wound healing, timing of closure, nor need for flap coverage compared to conventional dressings.
- Use of NPWT may be associated with a decreased inpatient hospital length of stay; however, this recommendation does not account for inpatient days spent awaiting outpatient therapy approval by an insurance company.
- Infectious wound complications are no different between NPWT and conventional dressings. The addition of silver to NPWT may decrease bacterial counts of *S. aureus* species.
- NPWT does not offer an improvement in quality of life compared to conventional dressings.

A Personal View of the Data

Despite a relatively limited amount of literature regarding its efficacy, NPWT has become an important tool used for the care of complex traumatic wounds. Combining its ubiquitous availability with provider ingenuity and experience, the care of many patients has potentially improved over the last 20 years because of NPWT. Indeed, NPWT likely has facilitated better control of wound output, less frequent need for dressing changes, and better pain control. However, these benefits are not necessarily substantiated in the scientific literature.

In our opinion, it is critically important to observe the standard principles of early excision of devitalized tissue, wide drainage, and rapid, efficient resuscitation.

For example, in patients with traumatic amputations, it is our practice to perform immediate operative debridement, open packing, and early re-exploration to reassess the extent of soft tissue damage. In our experience, the second inspection generally reveals further soft tissue injury that was not readily apparent at the first operation and occasionally leads to more tissue loss. Premature NPWT application before adequate debridement has the potential to delay the recognition of wounds that require further operative intervention. In our opinion, it is only after this second and thorough debridement that NPWT should be considered.

After this careful review, the literature surrounding NPWT is inadequate to answer many of the questions about this wound treatment paradigm. While there are pockets of relatively convincing evidence on long-term outcomes related to NPWT, there is a dearth of sound data that NPWT improves care in the acute setting. Indeed, like many innovations that have emerged in the care of trauma patients, the widespread implementation of NPWT has advanced quicker than the available evidence substantiating its efficacy. Accordingly, this field warrants further robust investigation as in certain situations, it likely has the potential to benefit trauma patients.

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Enterocutaneous Fistula Management in Trauma

7

Alexa P. Soult and Andrew J. Dennis

Introduction

Despite years of experience, we have not solved the dilemma of ECF development, but we continue to attempt to minimize the risks to our patients. Open abdomens especially, translate into a race to closure in order to prevent fistula formation. Fistulas, whether enteroatmospheric (EAF) or enterocutaneous (ECF), continue to challenge trauma surgeons worldwide.

Despite the decline in damage control laparotomies and the subsequent "open abdomen," fistulas remain a constant threat separating rapid recovery from protracted convalescence. The dreaded complication of ECF fistulas after trauma have an incidence up to 25% and are associated with significant morbidity and mortality, prolonged ICU and hospital stay with substantial financial burdens, all while requiring complex, methodical decision-making skills from multidisciplinary care team [1].

Search Strategy

The management of fistulas has dramatically changed over the decades and the search was limited to after the year 2000. A PubMed search was performed with the keywords: Enterocutaneous Fistula (ECF), Enteroatmospheric fistula (EAF), Trauma, Damage control laparotomy, nutritional support for enterocutaneous fistula, and endoscopic management of enterocutaneous fistula. There is a low number of high evidence papers due to the nature of the topic being retrospective and more

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Table 7.1 PICO

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Trauma patients with enterocutaneous fistula development	Nonoperative optimization and management followed by surgical repair	Nonoperative management without definitive repair	Mortality, morbidity, recurrence of fistula, primary fascial closure, wound care options, and nutritional outcomes

experienced-based management, therefore case studies were also included in our search strategy for management of enterocutaneous fistulas (Table 7.1).

Results

According to the AAST Prospect Open Abdomen Registry, having a large bowel resection, large volume resuscitation, and increased number of re-explorations increases the likelihood of developing enterocutaneous fistula, enteroatmospheric fistula, and intraabdominal sepsis [1]. The majority of patients with ECF have one or more hollow viscus injuries that are more likely colonic in nature. Dubose et al. demonstrated that the technical method of repair, stapled versus hand-sewn anastomoses, and ostomy creation versus anastomosis at the initial operation, was not an independent predictor of fistula development. However, the performance of a damage control surgery with pancreaticoduodenal injuries was a significant predictor of ECF [2]. Ultimately the longer the abdomen remains open, the greater the risk of ECF, and primary fascial closure is the primary goal. No matter the method of closure, all abdominal closures performed in a delayed fashion carry the risk of fistula formation. Therefore, the more rapidly a closure can occur, the less the risk [1, 3].

Fistulas: Patience, Do Not Panic

After recognizing a patient has an ECF, the essential next steps include addressing the metabolic and infectious issues. Control of the output is paramount and critical to avoid sepsis. Defining the anatomical location will guide the long-term strategies such as nutrition and wound care. This period takes time, patience, and focus. Common pitfalls include attempts at repair, failure to adequately address nutrition, and failure to control output.

Martinez et al. reviewed in their institution all postoperative patients with fistulas following operations during a 10-year period to identify factors related to spontaneous closure, need for operative treatment, and mortality. A total of 174 patients were treated. Postoperative enterocutaneous fistula closure was achieved in 151 patients (86%), being spontaneous in 65 (37%) and surgical in 86 (49%). Factors that significantly precluded spontaneous closure were jejunal site, multiple fistulas, sepsis, high output, and hydroelectrolytic deficit at diagnosis or referral. The authors concluded that controlling for volume loss, metabolic disturbances and sepsis is

instrumental in acutely decreasing further morbidity and mortality associated with ECF and EAF [4]. Ideally, percutaneous drainage, antibiotics, and wound care will suffice, however, reoperation for effective drainage may be necessary. Empiric antibiotics are recommended but limited to 4 to 7 days unless unable to obtain source control to limit antibiotic resistance [5]. Aggressive resuscitation cc for cc with appropriate replacement fluids may be necessary to meet physiologic parameters of resuscitation due to significant volume shifts. If surgical intervention is required for control of sepsis, the operation should be limited to wide effective drainage only. Although frequently tempting, definitive management must be deferred due high risk of fistula recurrence in the emergent setting [6].

Understanding the anatomic makeup of the fistula provides a road map for further management and potential operative planning down the line. The location of the fistula affects the volume of effluent as well as the specific composition and viscosity, which can drastically change the patients' metabolic, electrolyte, and nutritional responses [7]. Using a combination of cross-sectional imaging and fistulograms to define the anatomy, it will be evident of the source of the fistula, the nature of the tract, presence or absence of bowel continuity, distal bowel obstructions, and abscess cavities associated with the fistula [6]. Favorable fistula anatomy that is more consistently shown to close spontaneously entails those of esophageal, duodenal stump, pancreaticobiliary, and jejunal origins with small defects less than 1 cm and long tracts greater than 2 cm [6]. Fischer et al. in reviewing 10 years of experience of ECF formation after trauma laparotomy, identified that patients with open abdomens were more likely to develop fistulas from the small bowel in comparison to those whose abdomens were closed, and 37% of fistulas occurring with open abdomens closed spontaneously versus 45% of the fistulas that occurred in a closed abdomen, likely from unfavorable anatomy of short tracts, mucosal eversion, and large abdominal wall defects seen in the open abdomen group [8]. Early recognition of the location and patient history provides valuable information for the likelihood of future operative interventions and challenges that may arise, specifically with output and wound care needs.

The external loss of fluids through fistulas dictates a high versus low output fistula. Greater than or less than 500 mL per day is the cutoff for defining high output versus low output fistulas. Quantifying the output helps understand the potential electrolyte abnormalities and malnutrition that will develop within these patients. As such, low output fistulas are three times as likely to spontaneously close and mortality rates significantly increase with higher output fistulas [6]. For high output fistulas, efforts should focus on utilizing antimotility and antisecretory agents to help control output, ease wound care, and potentially allow for enteral nutrition [5]. When all fails, somatostatin or its' analog, Octreotide may have a role. While Octreotide has been shown to decrease output, it has not been shown to affect the rate of closure and currently, there is no evidence supporting the use of octreotide in ECF after trauma. An individualized plan for each patient and the use of octreotide should exist given the detrimental effects of high output fistulas [6, 9].

Long-term success of enterocutaneous fistula management depends largely on local wound care and channeling output away from skin. This phase focuses on

skin protection while containing and accurately measuring the effluent while preventing further wound complications [7]. Utilizing the assistance of collection bags, skin barriers, drains, enteric tubes, wet to dry dressings, negative pressure wound vacuums, and pouching systems are essential. Creativity is key and the best solution frequently requires "out of the box" thinking to isolate the fistula and control its drainage. Ostomy supplies, large pouching devices, catheters within fistula to direct output in combination with wet to dry dressings are all options to channel drainage. None is without complication, however, Skin breakdown, hypersensitivity of the skin due to adhesives, and frequent leaks remain the greatest challenge when it comes to ostomy appliances and dressings. Negative pressure therapy can assist in the management and healing of fistulas and surrounding wounds. It can also be beneficial in directing and controlling fistula output. Vacuum sponges can be quite effective at isolating the fistula and directing the output away from the remaining wound. This is especially valuable when the fistula is high output and low viscosity. Returns on value diminish the more distal the fistula as viscosity of the output can quickly clog the sponge. As with all adjuncts, negative pressure devices can have complications. They have been associated with further erosion of bowel loops and with additional fistula formation [10]. Each plan must be individualized and frequently requires trial and error. The most valuable and successful approaches involve a multidisciplinary approach that involves not only the surgeon, but invested nursing, wound care specialists, pharmacists, and nutrition expertise.

Nutrition support for patients with fistulas focuses on maintaining metabolic normalcy and promoting spontaneous closure, while optimizing for long-term operative interventions. Patients with newly identified ECFs suffer from significant metabolic and physiological stress leading quickly to acute malnutrition [5]. Total parenteral nutrition (TPN) should be initiated in early management of ECF. This allows for bowel rest to decrease output so as to improve initial wound care. Once this is achieved, however, we agree with others and advocate for early enteral nutrition [5]. Ultimately, the location of the fistula and associated fluid and calorie losses will dictate the route of nutrition. Enteral nutrition is always preferred as it is believed to maintain GI mucosal integrity and reduce bacterial translocation, thus offering a protective effect [11]. It has been shown that even with only 20% of required calories given enterally there is preserved mucosal integrity, immunologic and hormonal function, as well as hepatic protein synthesis [7]. Parenteral nutrition, on the other hand, has revolutionized the long-term management and mortality in patients unable to tolerate enteral nutrition. TPN remains highly impactful for circumstances such as intestinal discontinuity, short gut syndrome, inability to obtain enteral access, intolerance, increased ECF outputs with uncontrolled skin breakdown or fluid and electrolyte imbalances [2, 7]. High output fistulas will ultimately require 1.5 to 2 times the normal caloric intake due to ongoing losses, twice the normal vitamin supplementation, 5–10 times the vitamin C requirement as well as zinc, copper, folic acid, and B12 [7]. In all patients with fistulas, trending nutritional parameters of weight, prealbumin, albumin, transferrin, and C-reactive protein are essential to achieve an anabolic state, which

is essential for corrective operative planning. Of all nutritional values, albumin levels have been correlated to surgical morbidity and mortality thus stressing the importance of sound nutritional foundation.

Fistulas in the Open Abdomen

The concept of damage Control Surgery was a paradigm shift that decreased mortality by recognizing and prioritizing the associated metabolic disturbances associated with trauma. It calls for the abbreviation of surgery to correct only active bleeding and spillage while simultaneously addressing ongoing metabolic disturbances, hypothermia, and coagulopathy. This is frequently achieved by low crystalloid, high colloid resuscitations and delaying definitive operations, and large cavity closure. Unfortunately, with all good intentions come unintended consequences. As we leave abdomens open, the risk of fistula increases, thus putting the surgeon and patient on a clock to definitive closure. These patients have a fivefold increase in ECF development compared with patients whose abdomen is not closed at the initial laparotomy. Those closed after postoperative day 5 were associated with a fourfold increase in anastomotic leak rates [3, 12]. Additionally, patients who received large initial resuscitations have been shown to have higher rates of fistula development [1, 12]. Open abdomen patients are also highly catabolic and thus become malnourished early; this too elevates the fistula risk. However, many fistulas can be prevented by using a protective non-adherent covering of the hollow viscus, avoiding over resuscitation, avoiding serosal injury, and most importantly, prompt fascial closure, and early (starting within four days) enteral nutrition [2].

If a fistula develops, 4 core principles are paramount:

1. Prevent sepsis
2. Control effluent output
3. Prevent skin and soft tissue breakdown
4. Provide adequate nutrition

Open abdomen patients are extremely challenging. The best management is prevention by closure of the open abdomen with or without a fistula. In our practice, we employ a very aggressive "open abdomen protocol" that achieves primary abdominal closure. This eliminates style-based practice and has proven extremely successful. We do not allow abdomens to remain open and have a near 100% success rate at closure [13].

There are multiple means to reach fascial closure, each with its own risk for fistula development. The details of each, however, are beyond the scope of this chapter. We use transabdominal wall traction with tremendous success to achieve primary closure of the abdomen. Fistula rates are 12% (n = 4/32) over a 3-year-time period from 2008 to 2011 [13]. The intent is to prevent fistula formation, however, should it occur either before or during the process of abdominal closure, we continue to close the abdomen and exteriorize the drainage of the fistula. In our experience, closure over a fistula with extensive drainage frequently results in resolution of the fistula as the abdominal wall seals over it. Alternatively, if the fistula is in the

midline, we routinely exteriorize the fistula through the midline and attempt to close skin around it to channel the effluent in anticipation of appliance placement to control output.

Long-Term Maintenance

The maintenance phase continues with nutritional optimization, correcting electrolyte imbalances with fluid shifts, and local wound care. Patient comorbidities related to the ECF significantly influence the morbidity and mortality of operative interventions and adequate attention from physicians and patient dedication lead to better outcomes. In fact, medical management has been shown to decrease the need for operative interventions in 50% of patients [1].

Despite all efforts, fistulas may not spontaneously close and operative interventions will be required. Patients will routinely push to have surgery, and usually much sooner than the physician's timeline. There is no clear consensus for the ideal time for reoperation, but mortality rates and risk of re-fistulization influence the timing. Evenson et al. waited four months from index operation in comparison to Lynch et al. showed a median time of 6 months to reoperation with decreased re-fistulization after 12 weeks in comparison to early intervention between 2 and 12 weeks [6, 14]. In our experience, from the time the abdomen is closed, waiting a minimum of a year, sometimes two, to ensure the least hostile abdomen is ideal if possible. We recognize, however, there are no good scientific metrics for the best timing. In order to undergo reoperation for ECF after trauma, patients at our institution must meet specific metrics. Each patient must be at an optimal BMI (<30) to minimize mechanical forces opposing abdominal wall reconstruction. They must be exercising regularly to be maximally conditioned as there is significant deconditioning expected postoperatively. There is no smoking, tobacco, or marijuana. This is critical to reduce infection, maximize wound healing, and improve neovascularization. Prior to any intervention, patients with ECF need to be maximized nutritionally, evident by albumin, transferrin, and prealbumin levels ideally within normal ranges. Medical clearance is imperative for patients with comorbidities and for preventing other complications. Lastly, operative intervention does not mean a quick fix. Strong family support and a stable domicile ultimately lead to better outcomes [15]. Planning operative interventions is founded upon a strong doctor–patient relationship. It is a two-way street where patient compliance and "buy in" are equally, if not more important, than the physician skill set. The preoperative discussion must emphasize the need for two-directional trust, and the importance of meeting the metrics and rules outlined at the beginning of the discussion. It is a contract that must be adhered to. No operative plans should be offered unless patients buy into the global plan.

Prior to undertaking a major step of operative repair, it is imperative to outline the distinct benefits, but the very real risks associated with reconstruction. While

taking down a fistula hopefully improves quality of life, the downside includes the inability to fix the fistula and re-fistulization. This is in addition to the normal risks of bleeding, infection, and death seen with any operation. Similarly, to patient expectations, the surgeons must know their own limitations. Enterocutaneous fistulas require complex decision-making and an understanding of the operative process. Complex cases, may at times, be better managed by tertiary referral facilities who regularly manage such patients.

Surgical Management

Other than common principles of management, intraoperative techniques may vary. The overwhelming goal of preventing re-fistulization and abdominal wall closure with hernia repair requires meticulous performance. Sound surgical decision-making is of the utmost importance and depends on intraoperative findings. However, some technical tips should be considered. In a retrospective study from Lynch et al., there was a 20% overall fistula recurrence rate. This was seen at higher rates with over-sewing than with resection [14]. Similarly, in another small retrospective review, Brenner et al. showed that recurrence was more likely after stapled anastomosis than hand-sewn [16]. In our experience, ensuring adequate lysis of adhesions to the point that the bowel is not tethered and thus free for peristalsis. Ideally, a single reoperation may be desirable, but depending on the operative length of time, extent of resuscitation, resulting bowel edema, and need for a second look, staged operations may be necessary.

Recommendations Based upon the Data

Unfortunately, despite all efforts, fistulas may not close or re-fistulization occurs after operative intervention; however, novel techniques can prevent the potential need for reoperation. Most of the various techniques are discussed through case reports and case series and in general have similar methods of plugging the outflow tract but leaving the fistula in place.

Depending on the location, case reports exist for endoscopically closing the enterocutaneous fistula with an over-the-scope clip. This has demonstrated a closure rate of 86% for acute (less than 30 days old) and 33% for chronic fistulas (greater than 30 days old) [17]. Similarly, endoluminal stenting has been used to exclude the fistula and prevent output but presents challenges with migration [18]. Fibrin glue gelatin sponge, or a combination with a polyglactin plug can be injected into the fistulous tract to occlude and allow healing, but much of the experience stems from treating perianal fistulas with limited information for long-term success in ECF patients [10]. These are all possibilities for nonoperative management and should be kept within the surgeon's armamentarium.

Summary of Recommendations

- Controlling for volume loss, metabolic disturbances and sepsis are instrumental in acutely decreasing further morbidity and mortality associated with ECF and EAF (evidence quality moderate; strong recommendation).
- Continue to close the abdomen and exteriorize the drainage of the fistula. Closure over a fistula with extensive drainage frequently results in resolution of the fistula as the abdominal wall seals over the fistula (evidence quality weak; strong recommendation).

A Personal View of the Data

Enterocutaneous fistulas are complex problems requiring individualized management while adhering to the same general principles. After identifying an ECF, adequately treat any signs of sepsis and drain all fluid collections. Once stabilized, define the anatomy and optimize nutritional status that may require evolution from total parenteral nutrition to enteral nutrition, or a combination of both. Wound care can be a challenge, but many options exist with the ultimate goal of adequately directing the output while protecting the skin and preventing wound disruptions. While some will close on their own, reoperations may be necessary, but only after a significant time period to decrease associated mortality and complication profile. Each patient will dictate the best interventions and may include creative means for closure. Enterocutaneous fistulas ultimately require a multidisciplinary approach for the best outcomes and a continuous relationship between the surgeon and patient.

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Part III

Antimicrobial Management

8 Does Prophylactic Antibiotics for Emergent Tube Thoracostomy Decrease Rates of Infection?

Andy C. Lee and Maria Lucia L. Madariaga

Introduction

Thoracic injury occurs in approximately 60% of patients with trauma [1] and accounts for 20 to 25% of all trauma deaths annually [2]. Pneumothoraces and hemothoraces account for the majority of the findings in thoracic trauma [3]. Seventy to ninety percent of all patients with thoracic injuries requiring interventions are managed with tube thoracostomy, and the timing of antibiotics, or if any are given at all, still remains a controversial topic [4].

Previous studies report that 2%–25% of patients with isolated chest injury who undergo tube thoracostomy developed infective complications [5]. Post-traumatic empyema and pneumonia result in increased length of stay, cost, and morbidity to patients [3]. Over the past 40 years, multiple studies attempted to determine whether antimicrobial drugs administered at the time of tube thoracostomy prevent infectious complications. However, results have not been conclusive [1]. Though established in non-trauma settings, the value of prophylactic antibiotics in decreasing infectious complications after tube thoracostomy in trauma settings remains without a definitive conclusion. With traumatic hemo- and/or pneumothorax, however, the pleural cavity has already been violated and potentially contaminated, and antibiotic levels cannot be achieved before the injury, thus administration of antibiotics may not truly be "prophylactic" [3]. The aim of this chapter is to review all existing literature and provide evidence-based recommendations with regards to prophylactic antibiotics for trauma tube thoracostomy.

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Search Strategy

We searched for the terms "thoracostomy," and "trauma," and "antibiotics" in the PubMed database. We included all randomized controlled trials, retrospective studies, systematic reviews and meta-analyses. We excluded all editorials, case series and opinion pieces (Table 8.1). Only English manuscripts were included. We did not limit our analysis based on the year of publication to best understand the evolution of antibiotic usage throughout the time period. The results of all studies were then summarized in a table. In addition, we collected raw numerical data on number of infectious complications and number of total patients in each treatment arm from each available randomized controlled trial, prospective observational study and retrospective study. Odds ratio and 95% confidence intervals were calculated using a two-way table comparing number of infectious outcomes between the different treatment arms. We then constructed forest plots summarizing odds ratios extracted from all available studies.

Our search strategy identified 19 studies from 1977 to 2020. There were 12 single-center randomized controlled studies, one multicenter randomized controlled study, two multicenter observational prospective studies, two single-center retrospective studies, and two meta-analysis studies (Table 8.2). The clinical question as to whether or not prophylactic antibiotics are required to decrease infection rates for emergent chest tube placement is summarized in Table 8.3.

Table 8.1 Search strategy and article selection process

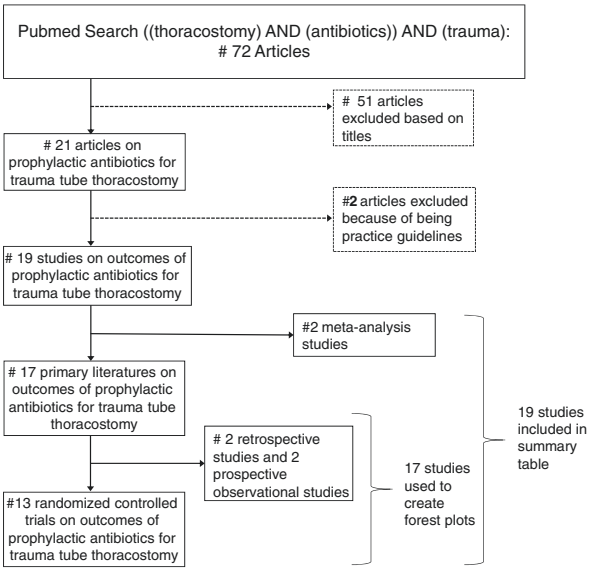


Table 8.2 Summary table of all randomized trials, retrospective studies, and meta-analyses on the use of antibiotics for thoracostomy following thoracic trauma in the PubMed database

Year	Study name	First author	Type of study	Type of trauma	Cohorts	Antibiotic used	Primary outcome	Result	Location	PMID
1977	Prophylactic antibiotics in the treatment of penetrating chest wounds. A prospective double-blind study	Grover	Single center, prospective, randomized double-blind study	Penetrating	38—ABX for duration to 1 day following removal for 5 days 37—Placebo	Clindamycin (300 mg IV q6h)	Pneumonia, empyema	Less infectious complication in ABX arm	USA	333188
1981	Cefamandole for prophylaxis against infection in closed tube thoracostomy	Stone	Single center, prospective, randomized double-blinded study	Blunt or penetrating or spontaneous pneumothorax	60—ABX for duration, terminating second day after removal 60—No ABX	Cefamandole (1 gm IV q6h)	Pneumonia, empyema	Less infectious complication in ABX arm	USA	7299867
1985	Prophylactic antibiotics and no antibiotics compared in penetrating chest trauma	Mandal	Single center prospective and randomized study	Penetrating	40—ABX for duration 40—No ABX	Doxycycline (200 mg IV first dose followed by 100 mg IV twice daily)	Pneumonia, empyema	Antibiotic arm not statistically better	USA	3925155
1985	Prophylactic antibiotics and closed tube thoracostomy	Leblanc	Single center, prospective randomized study	Blunt or penetrating or spontaneous pneumothorax	39—ABX for duration 46—No ABX	Cephapirin (1 gm IV)	Pneumonia, empyema	Antibiotic arm not statistically better	USA	3975798

(continued)

Table 8.2 (continued)

Year	Study name	First author	Type of study	Type of trauma	Cohorts	Antibiotic used	Primary outcome	Result	Location	PMID
1986	Tube thoracostomy and trauma--antibiotics or not?	LoCurto	Single center, prospective randomized study	Blunt or penetrating	30—ABX for duration terminating 6 h post removal 28—No ABX	Cefoxitin (1 gm IV q6h)	Empyema, pneumonia	Less infectious complications in ABX arm	USA	3795301
1990	The role of antibiotic therapy in the prevention of empyema in patients with an isolated chest injury (ISS 9–10): a prospective study	Brunner	Single center, randomized controlled study	Blunt or penetrating	44—ABX for duration 46—No ABX	Cefazolin (IV q6h)	Empyema, pneumonia	Less infectious complication especially empyema in ABX arm	USA	2213948
1991	Antibiotic prophylaxis in penetrating injuries of the chest	Demetriades	Single cente, randomized study	Penetrating	95—Single dose 93—ABX for duration	Ampicillin (1 gm IV or 1 gm IV followed by by 500 mg PO q6h)	Empyema, pneumonia, wound Sepsis	Single dose as effective as prolonged prophylaxis	South Aftica	1759762
1993	Antibiotic prophylaxis is indicated for chest stab wounds requiring closed tube thoracostomy	Cant	Single center randomized, double-blinded study	Penetrating (stabs)	57—ABX for 24 h 56—Placebo	Cefazolin (500 mg IV q8h)	Thoracotomy, significant Pyrexia, positive culture abnormal WCC	Favoring ABX arm	South Aftica	8495311

1994	Preventive antibiotic usage in traumatic thoracic injuries requiring closed Tube Thoracostomy	Nichols	Single center, prospective, randomized double blinded study	Blunt or penetrating	63—ABX for duration and stopped within 24 h of removal 56—No ABX	Cefonicid (1 gm daily)	Empyema, pneumonia	Less infectious complications in ABX arm	USA	7956409
1997	Posttraumatic empyema risk factor analysis	Aguilar	Single center retrospective case control study	Blunt or penetrating	40—ABX at time of thoracostomy 544—No ABX	Not specified	Empyema	Antibiotic arm not statistically better	USA	9197858
1998	Role of prophylactic antibiotics for tube thoracostomy in chest trauma	Gonzalez	Single center, prospective, randomized, double blinded study	Blunt or penetrating	71—ABX for duration 68—No ABX	Cefazolin (1gm IV q8h)	Pneumonia, empyema	Less infectious complications in ABX arm	USA	9655270
2004	Use of presumptive antibiotics following Tube Thoracostomyfor traumatic Hemopneumothorax in the prevention of empyema and pneumonia—A multi-center trial	Maxwell	Multicenter, prospective, randomized, double blinded study	Blunt or penetrating	77—ABX for duration 76—ABX for 24 h 71—No ABX	Cefazolin (1 gm IV q8h)	Empyema, pneumonia	Antibiotic arm not statistically better	USA	15514527
2009	Are antimicrobials useful in closed thoracostomy due to trauma?	Villegas-Carlos	Single center prospective, randomized, double blind, comparative study	Blunt or penetrating	63—ABX, duration unspecified 63—No ABX	Cefalotin	Empyema	Antibiotic arm not statistically better	Mexico	19344560

(continued)

Table 8.2 (continued)

Year	Study name	First author	Type of study	Type of trauma	Cohorts	Antibiotic used	Primary outcome	Result	Location	PMID
2012	Efficacy of antibiotic prophylaxis for preventing intrathoracic infections, after thoracostomy, for traumatic haemo/pneumothorax—Experience of Oradea county emergency hospital	Grigorescu	Single center, observational retrospective study	Not specified	86—ABX, duration unspecified 853—No ABX	Not specified	Empyema, pneumonia	Less infectious complications in ABX arm	Romania	23700905
2012	Systematic review and meta-analysis of antibiotic prophylaxis to prevent infections from chest drains in blunt and penetrating thoracic injuries	Bosman	Meta analysis of 11 prior randomized controlled trials	Blunt or penetrating	662—ABX, duration unspecified 572—No abx	Not specified	Overall infectious complications and empyema	Less infectious complications in ABX arm for penetrating injuries	N/A	22139619
2013	Risk factors for post-traumatic pneumonia in patients with retained haemothorax: Results of a prospective, observational AAST study	Bradley	Multicenter, prospective, observational study	Blunt or penetrating	126—ABX, duration unspecified 184—No ABX	Not specified	Pneumonia	Less infectious complication in ABX arm	USA	23433600

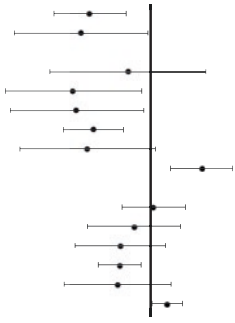
2014	Use of prophylactic antibiotics following tube thoracostomy for blunt chest trauma in the prevention of empyema and pneumonia	Heydari	Single center, randomized controlled study	Blunt	54—ABX for 24 h 50—Placebo	Cefazolin (2 gm IV for the first 24 h)	Empyema, pneumonia	Antibiotic arm not statistically better	Iran	24045157
2019	Presumptive antibiotics in tube thoracostomy for traumatic hemopneumothorax: a prospective, multicenter American Association for the Surgery of Trauma study	Cook	Multicenter, prospective, observational study	Blunt or penetrating	272—ABX 1615—No ABX	Not specified	Empyema, pneumonia	Antibiotic arm not statistically better	USA	31799417
2019	Use of prophylactic antibiotic in preventing complications for blunt and penetrating chest trauma requiring chest drain insertion: a systematic review and meta-analysis	Ayoub	Meta analysis of 12 prior randomized controlled trials	Blunt or penetrating	679—ABX, duration unspeficied 584—No abx	Not specified	Empyema, pneumonia	Less infectious complication in ABX arm	N/A	30899791

Abbreviations: *ABX* antibiotics

Table 8.3 P-Patients with emergent chest tube placement, I-antibiotic prophylaxis, C-antibiotic prophylaxis, no antibiotic coverage, and O-infection rates, pneumonia, and empyema

P	I	C	O
Patients with thoracic trauma	Emergency chest tube placement	Tube thoracostomy with antibiotic prophylaxis Tube thoracostomy without antibiotic prophylaxis Antibiotic duration Antibiotic selection	Rate of infectious complications • Pneumonia • Empyema

Study	Antibiotics Infection	Antibiotics No Infection	No Antibiotics Infection	No Antibiotics No Infection	Log Odds Ratio with 95% CI
Grover et al. 1977	5	33	19	18	-0.84[-1.34, -0.35]
Stone et al. 1981	1	59	8	52	-0.96[-1.88, -0.04]
Mandal et al. 1985**	0	40	1	39	-∞
Leblanc et al. 1985	1	25	2	24	-0.32[-1.39, 0.75]
LoCurto et al. 1986	1	29	8	20	-1.06[-2.00, -0.13]
Brunner et al. 1990	1	43	9	37	-1.02[-1.94, -0.10]
Cant et al. 1993	7	50	26	30	-0.79[-1.20, -0.38]
Nichols et al. 1994	1	62	6	50	-0.87[-1.81, 0.06]
Aguilar et al. 1997*	6	34	19	525	0.69[0.26, 1.11]
Gonzalez et al. 1998**	0	71	4	64	-∞
Maxwell et al. 2004	14	139	6	65	0.04[-0.40, 0.47]
Villegas-Carlos et al. 2009	3	60	5	58	-0.24[-0.88, 0.40]
Grigorescu et al. 2012*	2	84	51	802	-0.43[-1.05, 0.19]
Bradley 2013 et al.*	12	114	49	135	-0.43[-0.72, -0.14]
Heydari et al. 2014	2	52	5	45	-0.46[-1.19, 0.27]
Cook et al. 2019*	48	224	31	241	0.22[0.01, 0.43]



* Not randomized controlled, prospective studies

** Odds ratio not calculated and not shown on plot due to zero reported infectious complication in antibiotics arm

Graph 8.1 Incidence of infectious complications after tube thoracostomy- Comparing prophylactic antibiotics with no prophylactic antibiotics. Forest plot of odds ratios and 95% confidence intervals from all 19 primary literatures including randomized controlled trials, prospective observational studies and retrospective studies on post-traumatic infectious complications following tube thoracostomy in patients who had received prophylactic antibiotics to no prophylactic antibiotics. Of note, this plot is constructed utilizing odds ratios based on raw data provided by the original manuscripts and thus may not correspond to the original manuscripts' conclusion due to different statistical methods employed. (ie. Mandal et al., Nichols et al., Aguilar et al., and Grigorescu et al.)

Results

There has been no consensus on prophylactic antibiotics for trauma tube thoracostomy for reducing infectious complications, though eight out of sixteen studies included showed significantly reduced odds ratio of infectious complications following prophylactic antibiotics for tube thoracostomy compared to no antibiotics (Graph 8.1).

Among randomized controlled trials that compared frequencies of clinical intrathoracic infectious complications between patients who received antibiotics prophylaxis and patients who did not receive antibiotics prophylaxis for tube

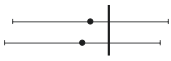
thoracostomy following chest trauma, six studies reported prophylactic antibiotics led to less infectious complications [6–11], while four studies reported prophylactic antibiotics had no significant effect on infectious complications [12–15]. The indications for tube thoracostomies among these studies included both blunt and penetrating chest injuries as well as spontaneous pneumothorax in two of the studies. Instead of looking at clinical development of pneumonia or empyema, one study randomized patients with stab chest injuries to either prophylactic antibiotics or placebo for 24 h following chest tube placements and reported prophylactic antibiotics decreased rates of thoracotomy for sepsis, length of hospital stay and frequencies of positive sputum cultures [16].

Duration of Antibiotics

While the efficacy of antibiotic usage may be controversial among numerous studies, few studies looked at the optimal duration of antibiotics usage (Graph 8.2). Demetriades et al. performed a single-center randomized controlled study randomizing patients to either a single dose of antibiotics at the time of tube thoracostomy or multiple doses of antibiotics for the duration of chest tube until removal and found single-dose antibiotics to be as effective as prolonged prophylaxis [17]. Maxwell et al. went further and performed a multicenter, randomized controlled, double-blinded study involving 224 patients randomizing patients into three groups—no antibiotics, antibiotics for 24 h following chest tube placement, and antibiotics for the duration of an indwelling chest tube. They reported empyema tended to occur more frequently in patients with penetrating injuries, though not statistically significant, and pneumonia occurred significantly more frequently in blunt than penetrating, while the duration of antibiotics usage did not affect the risk of empyema or pneumonia [18].

Two meta-analyses attempted to reconcile the mixed findings on the efficacy of prophylactic antibiotics on reducing post tube thoracostomy infectious complications in thoracic trauma. Bosman et al. in 2012 performed a meta-analysis on 11 randomized studies involving 1234 patients on antibiotic prophylaxis vs. no antibiotic prophylaxis in tube thoracostomy using Mantel–Haenszel pooled odds and reported a favorable effect of antibiotic prophylaxis on the incidence of pulmonary

Study	Prolonged Antibiotics		Short Course Antibiotics		Log Odds Ratio with 95% CI
	Infection	No Infection	Infection	No Infection	
Demetriades et al. 1991	8	85	10	85	-0.10[-0.52, 0.33]
Maxwell et al. 2004	6	71	8	68	-0.14[-0.63, 0.34]



Graph 8.2 Incidence of infectious complications after tube thoracostomy- Comparing prolonged prophylactic antibiotics with short course prophylactic antibiotics. Forest Plot of odds ratios and 95% confidence intervals from two available randomized controlled trials on post-traumatic infectious complications following tube thoracostomy in patients who had received prolonged duration prophylactic antibiotics to short course prophylactic antibiotics

infection. In a subgroup analysis, prophylactic antibiotics during tube thoracostomy for penetrating chest injuries reduced the risk of developing an infection, while prophylactic antibiotics during tube thoracostomy for blunt chest injuries did not [19]. Ayoub et al., in 2019, performed another meta-analysis on 12 randomized studies that included 1263 patients with isolated blunt and penetrating chest trauma. They found that prophylactic antibiotic, when compared with placebo alone, was associated with a four-time risk reduction in developing empyema (RR 0.25; 95% CI 0.13 to 0.49) and two-time risk reduction in developing pneumonia (RR 0.41; 95% CI 0.24 to 0.71) after chest tube insertion [5].

Antibiotic Selection

Antibiotic selection has not been uniform across all studies available. Seven of the listed studies used a first-generation cephalosporin [9, 11, 13–16, 18]. In the other studies other antibiotics, including ampicillin [17], second-generation cephalosporin [7, 8, 10], clindamycin [6] and doxycycline [12], were used. The infection rates reported in the studies that used ampicillin, clindamycin, and doxycycline were no different from those in the other included studies.

Few studies have investigated the side effects of antibiotic use for trauma tube thoracostomy. Maxwell et al. in their multicenter, randomized controlled, double-blinded study found a high incidence of antibiotic resistance in their patients. In their study, cultures from patients who received prophylactic antibiotics had grown *Enterococcus faecalis, Serratia marcescens*, beta-lactamase positive *Haemophilus influenza, Pseudomonas aeruginosa*, resistant strains *Streptococcus pneumonia*, and methicillin-resistant *Staphylococcus aureus*. This contrasts starkly with cultures from patients who did not receive prophylactic antibiotics, which were mostly sensitive *Staphylococcus* and *Streptococcus* species. Maxwell et al. thus recommended antibiotics not be administered routinely in injured patients in need of tube thoracostomy [18]. Cook et al. compared secondary outcomes including clostridium difficile colitis, hospital length of stay and death between patient who received prophylactic antibiotics for tube thoracostomy to those who did not, and reported no significant difference [1].

Recommendations Based on the Data

Even though there is significant heterogeneity of data on prophylactic antibiotics for trauma tube thoracostomy, all studies reported either no statistically significant difference or reduction in rates of infectious complications in patients who received prophylactic antibiotics compared to no prophylaxis. The two meta-analyses performed by Bosman et al. in 2012 and Ayoub et al. in 2019 [5, 19] both reported decreased infectious complications in patients who received antibiotic prophylaxis. These results support a conclusion favoring the administration of antibiotic

prophylaxis for patients with thoracic injuries requiring chest tube, with the most infectious risk reduction seen after penetrating chest injury [17, 18]. No specific antibiotic selection recommendation can be made based on the available results from the listed studies; however, a high number of studies utilized a first-generation cephalosporin. First-generation cephalosporins cover *Staphylococcus* and *Streptococcus* species, which are the most common organisms isolated from empyema cultures after tube thoracostomy. This implies contamination of the pleural space by skin flora as the most common route for intrathoracic infection in this setting [3, 6–8, 11–13, 16, 20].

Summary of Recommendations

- Prophylactic antibiotics should not be routinely given for trauma tube thoracostomy (evidence quality moderate; moderate recommendation).
- Prophylactic antibiotics may help reduce infections in penetrating chest injuries (evidence quality moderate; weak recommendation).
- A prolonged course of antibiotics for trauma tube thoracostomy is not recommended. (evidence quality moderate; strong recommendation).
- Antibiotic selection should cover skin flora (evidence quality moderate; moderate recommendation).

Personal View of the Data

Despite the potential benefits of prophylactic antibiotics for emergent tube thoracostomy based on the available data, we do not routinely administer antibiotics to patients requiring tube thoracostomy at our center. Studies have shown prophylactic antibiotics for emergent tube thoracostomy led to the development of resistant bacterial strains [18]. There is also a theoretical risk of *Clostridium difficile* colitis, allergic reactions, and delay in thoracostomy procedure while awaiting administration of antibiotics.

The Eastern Association for the Surgery of Trauma (EAST) Practice Management Guidelines Work Group has attempted to provide guidelines in regards to this matter. They first published a guideline on "presumptive" antibiotic use in tube thoracostomy for traumatic hemopneumothorax in 2000, reporting that there was sufficient Class I and II data to recommend presumptive use of antibiotics in patients undergoing tube thoracostomy for traumatic hemopneumothorax. They generated a Level 3 recommendation for presumptive antibiotics for the reduction in pneumonia, but not in empyema. The workgroup also concluded that a first-generation cephalosporin should be limited to 24 h if given before tube thoracostomy [21]. In 2012, EAST Practice Management Guidelines Work Group updated its practice guidelines and could not make a recommendation for or against the routine use of presumptive antibiotics in tube thoracostomy for traumatic hemopneumothorax to

reduce the incidence of empyema and pneumonia, and in addition, was unable to recommend an optimal duration of antibiotic prophylaxis due to insufficient data [3]. This reflected the practice of trauma surgery has continued to evolve based on evidence-based literature and the difficulty in providing a universally applicable guideline on this matter.

The decision to administer prophylactic antibiotics to trauma patients requiring tube thoracostomy should be more sophisticated. Several studies have attempted to identify risk factors for post-traumatic empyema or pneumonia in patients who required tube thoracostomy. Aguilar et al. in 1997, performed a retrospective analysis on 584 trauma patients who received tube thoracostomy at their center and reported retained hemothorax, pulmonary contusion, and multiple chest tube placement as risk factors predictive of the development of empyema [22]. They did not find the severity of injury, mechanism of injury, setting in which tube thoracostomy was performed, number of days chest tubes were in place, and lack of antibiotic administration to be risk factors for empyema development [22]. Maxwell in 2004 reported duration of tube placement and Thoracic Acute Injury Score were predictive of empyema [18]. Eren et al. in 2008 performed a retrospective study on 2261 patients with thoracic trauma who received tube thoracostomy. The group excluded patients who received prophylactic antibiotics. They identified prolonged duration of tube thoracostomy, length of intensive care unit stay, pulmonary contusion, laparotomy, and retained hemothorax as independent predictors of post-traumatic empyema [23]. Bradley et al. in 2013 reviewed the American Association for the Surgery of Trauma database on patients who received tube thoracostomy within 24 h of admission and reported injury severity score > 25, lack of prophylactic antibiotics, and blunt mechanism of injury to be independent risk factors for pneumonia in patients with post-traumatic retained hemothorax [24]. Perhaps the decision to give prophylactic antibiotics should be based on a combination of these risk factors. However, if emergent chest tube insertion is indicated, physicians should not delay this life-saving procedure for the administration of antibiotics.

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Antibiotics Prophylaxis after Penetrating Colon Injuries

9

Ahmad Zeineddin and Mallory Williams

Introduction

Management of penetrating injuries to the abdomen, and especially to the large bowel, has evolved significantly over the decades. The bacterial contamination of the peritoneal cavity and surgical wounds that are associated with these injuries have led to multiple studies in search of the appropriate prophylactic agent and regimen to avoid the resulting morbidity from surgical site infections (SSIs). Since the 1970s, preoperative administration of antibiotic prophylaxis has been common practice due to the significant decrease in SSIs compared to later administration of antibiotics. Similarly, antibiotic choice with anaerobic in addition to aerobic coverage has shown the same benefit. Multiple studies since then have evaluated the duration of antibiotic prophylaxis needed and examined more complex physiologic and injury-related confounders that would increase the risk for SSIs and therefore warrant different strategies. This review examines the current strategies of antibiotic use in these injuries.

Search Strategy

The MEDLINE database was searched using the following MeSH terms "penetrating," "abdominal trauma," "large bowel injury," "antibiotic prophylaxis." Articles were limited to the years 1999–2019. Only publications available in English language were included. Prospective randomized studies, as well as practice management guidelines, were included. Bibliographies of the review articles referenced were reviewed for additional studies not identified in our search (Table 9.1).

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Table 9.1 PICO

P (Patient population)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with penetrating colon injuries	Antibiotic prophylaxis (timing, coverage, duration)	Antibiotic prophylaxis (timing, coverage, duration)	Infection rates, abdominal complications

Results

The topic at hand has been studied well enough to provide high-level recommendations, with some areas that remain in need of higher-level evidence. The main questions involving antibiotic prophylaxis following colon injuries examine the antibiotic choice, the timing of administration of prophylaxis, the duration of prophylaxis, and the special circumstances that pose an exception to those rules.

Many studies prior to the period of this review have evaluated different antibiotic choices and their efficacy for hollow viscus and colon injuries. Namely, the prospective RCT in 1973 by Thadepalli et al. [1] demonstrating the need for broad-spectrum coverage including aerobic and anaerobic organisms. A summary of all the studies that followed comparing the different agents can be found in the EAST guidelines [2] evidentiary table (Table, Supplemental Digital Content 1, at http://links.lww.com/TA/A191). It is worth noting that current recommendations are against the use of aminoglycosides in trauma patients due to altered drug distribution pharmacokinetics during aggressive resuscitation demonstrated by Townsend et al. [3] in 1989 and Reed et al. [4] in 1992.

In our review, one study by Demetriades et al. [5] in 2001 in a large RCT studying different strategies of management of colon injuries found that single-agent prophylaxis had a higher complication rate 31% vs 16% compared to combination antibiotics (cephalosporin vs ampicillin/sulbactam in their study), which was an independent risk factor.

Timing of administration of antibiotics had also been answered by Fullen et al. [6] in 1973 showing a significant decrease in infection rates in patients with colon injuries receiving antibiotics preoperatively (11%) vs intraoperatively (57%) vs postoperatively (70%).

To answer the question regarding the duration of antibiotic prophylaxis, multiple randomized controlled trials have demonstrated the efficacy of a short ($\leq$ 24h) antibiotic prophylaxis course compared to long (5 days) course in preventing septic complications of colon injury (Table 9.2).

In 1999, Cornwell et al. [7] studied antibiotic prophylaxis for full-thickness colon injuries in high-risk patients with Penetrating Abdominal Trauma Index (PATI) >=25, transfusion of six units or more of packed red blood cells, or more than 4 h from injury to operation. This randomized controlled trial of 63 patients showed no significant difference between the two groups receiving 24-h vs 5 days of cefoxitin. Intra-abdominal infection rates were (1-day, 19%; 5-days, 38%), and extra-abdominal infections (1-day, 45%; 5-days, 25%). This study also performed a

Table 9.2 Summary of studies into duration of antibiotic prophylaxis

Study	Patients	Interventions	Results	Quality of evidence
Cornwell et al. (1999)	63 High-risk patients with penetrating abdominal trauma	1-day vs 5-days of cefoxitin	19% vs 38% intra-abdominal infection	High
Kirton et al. (2000)	317 Patients with hollow viscus injury	5-days vs 24-h of ampicillin/sulbactam	10% vs 8% SSI rate	High
Bozogzadeh et al. (2000)	300 Patients with penetrating abdominal trauma	24-h vs 5-days of cefoxitin	6.1% vs 5.9% intra-abdominal infection. 10.1% vs 11.2% wound infection	High
Delgado et al. (2002)	Retrospective review of 97 patients with penetrating abdominal trauma	Short vs prolonged antibiotics prophylaxis	14% vs 24% infection rate	Low

mini-meta-analysis using data from Fabian et al. [8] who also compared the use of cefoxitin or cefotetan in hollow viscus injuries, with a subset of high-risk patients with colon injuries that were used in this meta-analysis. They found a similar combined rate of abdominal infection of 11/58 (19%) in the 1-day group vs 20/61 (33%) in the 5-day group ($p = 0.13$), again showing no difference in infection rates with prolonged antibiotic prophylaxis.

In 2000, Kirton et al. [9] in another prospective randomized controlled study, comparing 24 h vs 5 days of ampicillin/sulbactam showed no difference in infection rate between the groups. The study included all hollow viscus injuries with colon injuries comprising 82/159 patients in the 5-day group and 80/158 patients in the 24-h group. SSI rates were 10% (16/159) and 8% (13/158) ($p = 0.74$) in the two groups, respectively. Even though there was no difference in infection rates between the two antibiotic groups, colon injuries were an independent risk factor for SSI compared to other hollow viscus injuries.

Bozorgzadeh et al. [10] demonstrated similar findings in another RCT in 2000 examining 300 patients with penetrating abdominal trauma, receiving 24 h vs 5 days of cefoxitin. Colon injuries were distributed equally (16/148 vs 16/152). There was no significant difference in general infection rate (27.7% vs 23%, $p = 0.35$), intra-abdominal infections (6.1% vs 5.9%, $p = 0.95$), or superficial (wound) infections (10.1% vs 11.2%, $p = 0.77$). In a multivariate model looking at duration of prophylaxis, organs injured, and shock, colon injury was the strongest independent risk factor for infection regardless of duration of therapy, which was not by itself an independent predictor of infection.

A retrospective review by Delgado et al. [11] in 2002 showed almost doubling of the infection rate in patients receiving prolonged antibiotic regimen following penetrating hollow viscus injuries with 14% vs 24% which, however, did not reach

statistical significance ($p = 0.273$). Limitations to this study preventing meaningful interpretation of these results include its retrospective nature, and the fact that colon injuries were not separated from other hollow-viscus injuries

There still exist some special circumstances that might complicate the antibiotic prophylaxis regimen in penetrating colon injuries. One being the increasing evidence for and use of damage-control laparotomy (DCL) in a multi-trauma scenario. A review of the literature shows no published prospective trials evaluating the question of antibiotics then. One retrospective review by Goldberg et al. [12] in 2017 showed significant variations in the use of antibiotics in patients undergoing DCL compared to primary closure with a trend toward a longer course of antibiotics. This lack of literature in relation to DCL, which is ever-increasing in use demonstrates the need for a prospective trial and higher-level evidence to guide practice. Another issue that might complicate antibiotic prophylaxis in colon injury is the presence of hemorrhagic shock. Many studies reference Ericsson et al. [13] study from 1989 comparing low- and high-dose clindamycin combined with amikacin showing a decreased infection rate in the higher-dose group, attributed to a more stable measured serum concentration in a higher than anticipated volume of distribution due to ongoing resuscitation. These findings have not been replicated since, so there is a similar need for further studies to provide higher-level evidence to guide this practice.

Recommendations Based Upon Data

Penetrating injury to the large bowel is associated with high-infection related morbidity, and the emotional and economic costs to the patient is not inconsequential. The most significant risk of developing an infection after a penetrating injury to the colon is predicated upon simply having a colon with a penetrating perforation. The chose of antibiotic prophylaxis, timing and duration is required to mitigate the infectious sequeale.

Summary of Recommendations

- Patients with penetrating colon injury should receive preoperative, broad-spectrum antibiotics, to cover aerobic and anaerobic bacteria, for no more than 24 h (Evidence quality high; Strong recommendation).
- Higher doses of antibiotics are needed in the presence of hemorrhagic shock with redosing after ten units of blood products (Evidence quality low; Weak recommendation).
- No recommendation can be made regarding duration of antibiotic prophylaxis in Damage-Control Laparotomy.

Personal View of the Data

Our practice has been guided by the evidence with most patients receiving broad-spectrum antibiotics initiated in the trauma bay in preparation for surgical intervention. The antibiotic of choice is usually a second-generation cephalosporin or a combination (piperacillin/tazobactam). This usually is continued for 24 h in most patients. In the case of DCL, antibiotics are usually continued until 24 h following closure of the abdomen.

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Antibiotic Regimen in Treating Complicated Intra-abdominal Infections

10

Melissa Linskey Dougherty and Scott B. Armen

Introduction

Complicated intra-abdominal infections (cIAI) are a common pathology encountered by trauma, acute care, and critical care surgeons. Perforated viscus, hepatic injury, and pancreatic injury or necrosis all leave patients vulnerable to cIAI. While the causes of cIAI are diverse, their management strategies can be quite similar. It is crucial that antimicrobial therapy be started promptly, and the therapy selected be appropriate to cover organisms typical to these infections. Although beyond the scope of this review, source control—draining abscesses, control of gastrointestinal tract violation, and removal of necrotic tissue—is of utmost importance for successful management of cIAI.

Patients may present with sepsis or septic shock, and mortality risk is significant, with a rate as high as 10.5% in one multinational study [1]. Bacterial resistance can impair the ability of the trauma surgeon to effectively and efficiently treat cIAI, particularly in hospital-associated infections. Factors associated with increased risk of treatment failure or death from cIAI include advanced age greater than 70, malignancy, cardiovascular compromise, liver disease or cirrhosis, renal disease, hypoalbuminemia, diffuse peritonitis, delayed or inadequate source control, delayed or inadequate antimicrobial choice, or presence of resistant pathogens [2]. High-risk patients need broad coverage, even in CA-IAI.

For the purpose of this review, cIAI refers to infections that extend beyond the organ of origin causing localized or diffuse peritonitis [3]. Complicated IAI may further be classified as community-acquired (CA-IAI) or hospital-associated (HA-IAI). These distinctions become important in choosing appropriate

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antimicrobial therapy; however, duration of therapy should not typically be impacted by this difference if adequate source control has been obtained. HA-IAI criteria include those that develop 48 hours or more after source control, admissions greater than 48 hours duration in the last 90 days, residence in a nursing facility during previous 30 days, home therapy or dialysis in the last 30 days, or broad-spectrum antibiotics for 5 days or more in the previous 90 days [2].

In a global sampling of nearly 1900 patients, the majority presented with community-acquired infections, with only about 13% deemed healthcare-associated. Source control was achieved in 91.4% of these patients with either surgery (open or laparoscopic) or percutaneous drainage. The most common cause of cIAI was appendicitis, followed by postoperative infection, cholecystitis, gastroduodenal perforation, colonic, and small bowel perforations [1].

Common organisms found in intra-abdominal infections include Gram-negative bacilli, anaerobes, and Gram-positive cocci. Proximal small bowel contains enterococci and *Escherichia coli*. Distal small bowel contains increasing Enterobacteriaceae species and anaerobes, predominantly Bacteroides. The colon contains high bacterial counts with anaerobes predominating [4]. The most common aerobic organisms isolated from cultures are *Escherichia coli*, *Enterococcus faecalis*, *Klebsiella pneumoniae*, *Streptococcus*, *Pseudomonas*, *Enterobacter*, and *E. faecium* [1]. Resistant organisms such as methicillin-resistant *Staphylococcus aureus* (MRSA), extended-spectrum beta-lactamase (ESBL) producing organisms, vancomycin-resistant enterococcus (VRE), and *K. pneumoniae* carbapenemase (KPC) organisms present challenges to antibiotic selection.

Several societies have confronted the topic of cIAI antibiotic therapy including the World Society of Emergency Surgery (WSES), Infectious Disease Society of America (IDSA), and the Surgical Infection Society (SIS), with the most updated recommendations from 2017 from both WSES and SIS [2, 3]. Commonly used antibiotic regimens include beta-lactams such as penicillin-like agents, cephalosporins, carbapenems, and fluoroquinolones as single agent or in combination with metronidazole. Less commonly used agents such as aztreonam, tigecycline, vancomycin, and aminoglycosides may be useful in situations of severe allergy or resistance.

Search Strategy

Our search strategy was to use the terms ((“2000”[Publication Date]: “2020”[Publication Date]) AND (“controlled clinical trial”[Publication Type] OR “meta-analysis”[Publication Type] OR “randomized controlled trial”[Publication Type])) AND ((complicated[All Fields] AND (“infections”[MeSH Terms] OR “infections”[All Fields] OR “infection”[All Fields])) AND intra-abdominal[All Fields]) AND (“anti-bacterial agents”[Pharmacological Action] OR “anti-bacterial agents”[MeSH Terms] OR (“anti-bacterial”[All Fields] AND “agents”[All Fields]) OR “anti-bacterial agents”[All Fields] OR “antibiotics”[All Fields]) on PUBMED. Supplementary search included retrieving guidelines by World Society

Table 10.1 PICO Questions regarding antibiotic regimen in patients with complicated intra-abdominal infections

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with complicated intra-abdominal infections	Antibiotics	Other regimens	Efficacy, mortality, adverse events

Table 10.2 PICO Questions regarding duration of antibiotic therapy in complicated intra-abdominal infection

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with complicated intra-abdominal infections	Short-course antibiotics	Long-course antibiotics	Antibiotic-free days, Recurrent infection, need for additional source control, mortality, emergence of resistant organisms

for Emergency Surgery and Surgical Infection Society from which additional resources were identified.

Clinical questions to be answered including how to determine the most effective antibiotic regimens to treat complicated intra-abdominal infections and the duration of therapy with the goal to avoid recurrent infection, mortality, and with minimal adverse events (Tables 10.1 and 10.2).

Results

Antibiotic Choice

Inappropriate or delayed initial antibiotic therapy has been associated with worsened patient outcomes, including increased length of stay, hospital costs, and mortality [5]. Many randomized controlled trials (RCTs) have compared antibiotic regimens head to head to assess efficacy. When choosing an empiric antibiotic regimen for cIAI, one needs to consider the likely suspected organism, side effects particularly in the setting of pre-existing organ dysfunction, local resistance patterns, and the formulary of the institution. WSES and SIS have performed extensive analyses of antibiotic regimens to treat cIAI utilizing GRADE technique [2, 3]. The reader is referred to these resources for an extensive review of antibiotic regimens.

Favorable Clinical and Microbiological Response

In RCTs comparing antibiotic regimens, favorable clinical response is typically defined as resolution of infectious findings, no need for further surgery or additional antibiotics, or lack of development of secondary, recurrent, or superinfections. Microbiological response is defined as eradication of organisms on subsequent cultures. Table 10.3 [6–24] highlights a sampling of such trials. Unless discussed below, in these trials and meta-analyses, there were either equivalence or no significant differences in clinical or microbiological efficacy.

Table 10.3 Randomized controlled trials and meta-analyses of antibiotic regimens for complicated intra-abdominal infections

Intervention antibiotic class	Study	Patients	Intervention	Comparator	Efficacy (Clinical and microbiological)	Mortality	Adverse events (all-cause)	Quality of evidence
Penicillin-like agents	Erasmo et al. (2004) [6]	293	Piperacillin/ Tazobactam ($n = 149$)	Imipenem/ Cilastatin ($n = 144$)	No difference. Clinical: 83.2 vs. 87.5% Micro: 85.1 vs. 91.6%	Not well enumerated	No difference. All: 26.8 vs. 36.1%, Drug-related: 8.1 vs. 8.3%	High
	Catena et al. (2013) [7]	142	Ampicillin/ sulbactam ($n = 71$)	Ertapenem ($n = 71$)	**Favors Ertapenem. Clinical: 86 vs 97%**	Not well enumerated	**Higher infections in ampicillin/sulbatam group.**	Moderate
Cephalosporins	Barie et al. (1997) [8]	323	Cefepime plus metronidazole ($n = 95$)	Imipenem/ Cilastatin ($n = 122$)	**Favors Cefepime in protocol-valid, not in ITT. Clinical: 82 vs. 76% Micro: 82 vs. 76%**	Favors Cefepime. 2 vs. 7%	No difference. 24 vs. 24%	High
	Garbino et al. (2007) [9]	122	Cefepime plus metronidazole ($n = 60$)	Imipenem/ Cilastatin ($n = 61$)	**Favors Cefepime. Clinical: 87 vs. 72% Micro: 71.6 vs. 62.3%**	No difference. One death per group attribute to comorbidity.	No difference. 25 vs. 23%	High
	Mazuski et al. (2016) [10]	1043	Ceftazidime-Avibactam plus metronidazole ($n = 520$)	Meropenem ($n = 523$)	Noninferior. Clinical: 82.5 vs. 84.9% Micro: similar	2.5 vs. 1.5%	No difference. 45.9 vs. 42.9%	High
	Solomkin et al. (2015) [11]	993	Ceftolozane-Tazobactam plus metronidazole ($n = 487$)	Meropenem ($n = 506$)	Noninferior. Clinical: 83 vs. 87.3% High success in ESBL with TOL-TAZ	2.3 vs. 1.6%	No difference. 44 vs. 42.7%	High
	Lucasti et al. (2014) [12]	121	Ceftolozane-Tazobactam plus metronidazole ($n = 82$)	Meropenem ($n = 39$)	**Favors meropenem Clinical: 83.6 vs. 96% Micro: 90.6 vs. 95.8%**	3 deaths in TOL-TAZ, not attributed to drug	No difference. 50 vs. 48%	Moderate

Carbapenems	Solomkin et al. (2003) [13]	633	Ertapenem ($n = 311$)	Piperacillin/ Tazobactam ($n = 304$)	Equivalent. Clinical: 79.3 vs. 76.2% Micro: 86.7 vs. 81.2%	6.4 vs. 3.6%	Not well enumerated	High
	Dela Pena et al. (2006) [14]	370	Ertapenem ($n = 178$)	Piperacillin/ Tazobactam ($n = 183$)	No difference. Clinical:82 vs 85% Micro: 94 vs. 98%	No difference. 2.8 vs. 4.7%	No difference. 54.4 vs. 55.3%	High
	Yellin et al. (2002) [15]	220	Ertapenem 1 g ($n = 59$), Ertapenem 1.5 g ($n = 51$)	Ceftriaxone plus metronidazole ($n = 55$x2)	No difference. Clinical: 1 g 89 vs 83%, 1.5 g 85 vs. 76% Micro: 1 g 88 vs. 85%, 1.5 g 88 vs. 75%	1 death in ertapenem group, not drug-related	No difference. 26% vs. 26%	Moderate
	Navarro et al. (2005) [16]	450	Ertapenem ($n = 225$)	Ceftriaxone plus metronidazole ($n = 225$)	No difference. Clinical: 93.2 vs. 93.1% Micro: 97.9 vs. 96.7%	4 vs 2 deaths, not drug-related	No difference. 49.3 vs. 45.8%	Moderate
Fluoroquinolones	Starakis et al. (2003) [17]	135	Ciprofloxacin plus metronidazole ($n = 69$)	Ceftriaxone plus metronidazole ($n = 66$)	Equivalent. Clinical: 94.2 vs. 89.4% Micro: 93 vs. 88.3%	1 vs 2 deaths	No difference. 14.1 vs. 5.6%	Moderate
	Malangoni et al. (2006) [18]	379	IV/PO Moxifloxacin ($n = 183$)	Piperacillin-tazobactam and amoxicillin-clavulanic acid ($n = 196$)	**Moxifloxacin favored in HA-IAI. No difference overall. Clinical: 80 vs. 78% Micro: 78 vs. 77%**	6 vs 7 deaths, none drug-related	No difference. 84 vs. 83%. High GI complaints.	High
	Solomkin et al. (2009) [19]	364	Moxifloxacin ($n = 180$)	Ceftriaxone plus metronidazole ($n = 181$)	Noninferior. Clinical: 87.2 vs. 91.2% Micro: 89.4 vs. 95.9%	No deaths	No difference. 31.7 vs. 24.3%	High
	Weiss et al. (2009) [20]	595	IV/PO Moxifloxacin ($n = 246$)	Ceftriaxone plus metronidazole and amoxicillin-clavulanate ($n = 265$)	Noninferior. Clinical: 80.9 vs. 82.3% Micro: 78.9 vs. 81.3%	No difference. 4.2 vs. 5.1%	**Higher QT prolongation in moxifloxacin.**	High
	Mavros et al. (2019) [21]	4125 (7 trials)	Moxifloxacin (4 studies), Ciprofloxacin (3 studies)	Beta-lactam based regimens	No difference. ITT RR 0.97 (95% CI 0.94–1.01)	No difference. RR 1.04 (95% CI 0.75–1.43)	No difference. RR 0.97 (95% CI 0.7–1.33)	High

(continued)

Table 10.3 (continued)

Intervention antibiotic class	Study	Patients	Intervention	Comparator	Efficacy (Clinical and microbiological)	Mortality	Adverse events (all-cause)	Quality of evidence
Tigecycline	Oliva et al. (2005) [22]	825	Tigecycline ($n = 413$)	Imipenem-cilastatin ($n = 412$)	Noninferior. Clinical: 73.5 vs. 78.2% Micro: 80.6 vs. 82.4%	17 vs. 12 deaths	**Higher rates of secondary infections, dyspnea, pneumonia, and hypoproteinemia in tigecycline group**	High
	Towfigh et al. (2010) [23]	448	Tigecycline ($n = 228$)	Ceftriaxone plus metronidazole ($n = 220$)	Noninferior. Clinical: 64 vs. 71% Micro: Monomicrobial 68 vs. 71.5%, Polymicrobial 67 vs. 68.3%	4 vs 3 deaths	**Tigecycline: higher nausea, oral thrush, leukocytosis, and DVT. Ceftriaxone: higher edema, atelectasis, taste change**	High
Aminoglycosides	Falagas et al. (2017) [24]	3177 (28 trials)	Clindamycin/ aminoglycoside	Beta-lactam monotherapy	**Beta-lactams more effective. OR 0.67 (95% CI 0.55–0.81)**	No difference. OR 1.25 (95% CI 0.74–2.11)	Higher nephrotoxicity in aminoglycoside regimens OR 3.7 (95% CI 2.09–6.57)	High

Aminoglycosides in combination with clindamycin were once the gold standard to treat intra-abdominal infections. In a 2005 Cochrane review of antibiotic regimens to treat secondary peritonitis, any other regimen was favored over then gold standard combination aminoglycoside and clindamycin for clinical success (OR 0.65, 95% CI 0.46–0.92). Microbiological success also was favored in other regimens versus aminoglycosides (OR 0.49, 95% CI 0.31–0.76) [4]. A meta-analysis of 28 RCTs of beta-lactams over aminoglycoside plus clindamycin regimens, beta-lactams were favored for clinical success (OR 0.67, 95% CI 0.55–0.81) [24].

In a single institution RCT, ampicillin/sulbactam was statistically significantly less effective than ertapenem, 86% versus 93% in mild-to-moderate localized peritonitis [7]. In another small RCT, ampicillin/sulbactam was an independent predictor of treatment failure compared to moxifloxacin [25]. Cefepime and metronidazole were compared to imipenem-cilastatin in two RCTs conducted 10 years apart. Clinical and microbiological efficacy of cefepime and metronidazole were 82–87% and 71.6–82%, respectively. In both studies, cefepime and metronidazole performed statistically better than imipenem–cilastatin, with clinical cure of 72–76% and bacteriological success in 62.3–76% [8, 9]. Moxifloxacin as a single agent has been compared to piperacillin–tazobactam and ceftriaxone plus metronidazole [18, 19]. In a subgroup analysis of HA-IAI, moxifloxacin (IV/PO) performed better than piperacillin–tazobactam converted to amoxicillin–clavulanate (82 vs. 55%) [18]. In a small study comparing ceftolozane–tazobactam plus metronidazole with meropenem in cIAI, meropenem had higher clinical success rates in the modified intention to treat group; though, this was attributed to higher rates of missing data in the ceftolozane group [12].

Mortality

As seen in Table 10.3, mortality was either not well enumerated in RCTs comparing antibiotic regimens in cIAI or rates were low and not statistically different. The 1997 Barie et al. study comparing cefepime plus metronidazole with imipenem/cilastatin demonstrated lower mortality rates in the cefepime group [8]. Tigecycline stands out for mortality risk and carries a black box warning after meta-analyses not specific to intra-abdominal infections were performed and revealed a small, but statistically significant increased risk of mortality in patients who received tigecycline [26, 27].

Adverse Events

Antibiotic regimens for cIAI have rarely been attributed to serious adverse outcomes. Commonly, antibiotics cause gastrointestinal distress including nausea, vomiting, diarrhea, *Clostridium difficile* infection, and transaminitis. Other adverse events include nephrotoxicity and QT prolongation. Ampicillin–sulbactam use was complicated by more frequent superficial and deep surgical site infections when compared to Ertapenem [7]. Compared to beta-lactam antibiotics, aminoglycosides were associated with higher odds of nephrotoxicity (OR 3.7, 95% CI 2.09–6.57), but not ototoxicity [24]. Moxifloxacin was associated with higher rates of QT prolongation when compared to ceftriaxone and metronidazole [20]. Tigecycline use is

associated with higher rates of secondary infections, dyspnea, pneumonia, nausea, oral thrush, and DVT against comparators [22, 23].

Duration of Antibiotic Therapy

Duration of antibiotic therapy for cIAI has been investigated recently given the lack of evidence-based recommendations. The data come from patient populations that have undergone adequate source control. Duration of therapy in patients who have not had source controlling procedures is less clear, and this requires individualized clinical decision making.

Two multi-institutional randomized control trials attempted to answer the question if shorter antibiotic duration could effectively treat cIAI following source control. The STOP IT trial compared short-course antibiotics with a median 4 days versus discontinuation of antibiotics 2 days after resolution of fever, leukocytosis, and ileus with a maximum duration of 10 days of antibiotics, with a median duration of 8 days. The primary outcome of the STOP IT trial was an aggregate measure of subsequent surgical site infections, recurrent intraabdominal infection, or death within 30 days. While the study population did not meet the number of participants needed to meet statistical power, there was no difference found between the two groups at interim analysis, and the study was halted early [28]. The DURAPOP trial compared a short course of 8 days to longer course of 15 days of antimicrobial therapy in a critically ill population with cIAI with the primary outcome being antibiotic-free days between day 8 and 28 [29]. Other important secondary outcomes in these studies included but were not limited to extra-abdominal infection, need for additional source control, and antibiotic resistance emergence. In both the STOP IT and DURAPOP trials, the authors concluded that there was no apparent benefit to longer-course antibiotic therapy in their study populations [28, 29].

Antibiotic-Free Days

In the DURAPOP study, antibiotic-free days were the primary outcome for which the study was powered to detect a difference. Shorter-course therapy is associated with more antibiotic-free days in both the STOP IT (Median 25 vs. 21 days) and DURAPOP (Median 15 vs. 12 days) studies [28, 29].

Recurrent Infection and Extra-Abdominal Infection

No differences were detected in recurrent infection in either the DURAPOP or the STOP IT trials, but neither of these studies were powered for this individual outcome. In the STOP IT trial, short-course infection recurrence was 15.6%, while long-course was 13.8%. Surgical site infections in these patients were 6.6% and 8.8%, in short and long course groups. Extra-abdominal infections occurred in 8.9% of the short-course and 5% of the longer-course group [28]. DURAPOP included recurrent infection only in those who underwent additional procedures—13 of 14 versus 14 of 19 patients, and superinfection in those still admitted at day 28–11 of

32 versus 14 of 44, long course versus short course, respectively. These were not statistically significant [29].

Need for Additional Source Control

The DURAPOP study did not show difference in reoperation or additional drainage procedures between the shorter- and longer-course antibiotic regimens, 40% and 28%, respectively [29]. STOP IT does not investigate this outcome.

Mortality

In both the STOP IT and the DURAPOP trials, there was no statistically significant difference in mortality rates among short or longer-duration antibiotic therapy. STOP IT 30-day mortality rates were quite low with 1.2% in shorter-course group and 0.8% in longer-course group, highlighting the less critically ill population included in this study [28]. DURAPOP 45-day mortality rates were 11% vs 15% for short- and long-course antibiotic therapies, respectively [29]. Neither study was powered to detect a difference in this as an individual outcome.

Emergence of Resistant Organisms

In the STOP IT trial, emergence of resistant organisms was an uncommon occurrence and did not differ between the groups. Surgical site infection or recurrent infection with a resistant organism occurred in 2.3% of short-course and 3.5% of long-course groups. Extra-abdominal infection with resistant organisms occurred in 0.8 and 2.3% in the short and long-course groups, respectively [28]. There was no difference in the rates of emergence of resistant organisms between the groups in the DURAPOP study, with 43% of the short-course group and 50% of the longer-course group. It should be noted that the high rate of resistance in DURAPOP was from both surveillance cultures and clinical isolates taken as part of the protocol [29].

Recommendations Based on Data

Antibiotic Choice

1. We recommend using piperacillin–tazobactam as a single agent option for empiric therapy in high-risk community-acquired cIAI and hospital-associated cIAI.
2. We suggest avoiding ampicillin–sulbactam as empiric therapy for cIAI.
3. We recommend ceftriaxone and metronidazole as an option for empiric treatment of community-acquired cIAI.
4. We recommend cefepime and metronidazole as an option for empiric therapy in high-risk community-acquired cIAI and hospital-associated cIAI.
5. We recommend ertapenem as an option for community-acquired cIAI.
6. We suggest that carbapenem antibiotics other than ertapenem be used with suspected or confirmed ESBL organisms in cIAI.

7. We suggest that fluoroquinolones be employed in setting of allergy, culture-proven sensitivity given concern for increasing Gram-negative resistance.
8. We suggest that tigecycline with its broad coverage, although higher associated adverse outcomes including mortality, should be considered only as a last resort therapy.
9. We suggest novel cephalosporin/beta-lactamases be used in the setting of MDRO cIAI keeping in mind antibiotic stewardship.
10. We recommend utilizing aminoglycoside-based regimens only in response to resistant pathogens sensitive to these agents and not as initial empiric therapy.
11. We suggest metronidazole as anti-anaerobic agent of choice given increasing resistance of *Bacteroides* species to clindamycin.

Duration of Therapy

1. We recommend 3–5 days of antibiotic therapy following adequate source control in non-critically ill patients.
2. We suggest 3–8 days of therapy in critically ill or septic patients following initial source control, individualizing care based on the needs of the patient's clinical picture.
3. We suggest that clinician judgment be employed in determining antibiotic duration in circumstances of persistent sepsis or inability to obtain adequate source control in cIAI.

Personal View of the Data

For complicated intra-abdominal infections, our first-line therapy is either piperacillin–tazobactam or cefepime and metronidazole for higher risk CA-IAI or HA-IAI. For low-risk CA-IAI, we typically select ceftriaxone or ciprofloxacin, plus metronidazole. If and when culture results are available, antibiotics are accordingly tailored. We typically choose an antibiotic duration of 5 days from source control in both non-critically and critically ill patients. This duration is most frequently altered in critically ill patients with persistent sepsis.

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11 Is Vaccine Prophylaxis Necessary for Patients Undergoing Splenic Embolization?

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Introduction

It is well established that there is a significant risk of infection after splenectomy, and immunizations against encapsulated bacteria such as *Streptococcus pneumoniae*, *Haemophilus influenza type b*, and *Neisseria meningitidis* are necessary to prevent future infections, particularly overwhelming post-splenectomy infection (OPSI) [1–4]. While the reported prevalence of OPSI is low with a lifetime risk of 5%, it carries a mortality rate of 38–70% [2, 3, 5]. In patients with blunt injuries to the spleen, nonoperative management such as adjunctive angiography with embolization, or splenic artery embolization, is preferred over splenectomy for many patients [6]. The major advantage of nonoperative management of patients with splenic injury is the lower risk of complications, including infections given the preservation of splenic function.

While embolization for traumatic splenic injuries has been widely accepted in practice, questions pertaining to immune function and the need for vaccination following the procedure remain. The Advisory Committee on Immunization Practices (ACIP) recommends providing immunizations for patients who are not only asplenic but also those patients with <50% intact spleen, as these patients are at potential risk of infection and should follow the same vaccination recommendations as those patients undergoing an unplanned splenectomy [4, 7]:

- On the day of discharge or day 14 following procedure (whichever comes first):
  - Pneumococcal conjugate vaccine (PCV13).
  - Haemophilus influenza type b vaccine (Hib).

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  - Meningococcal conjugate vaccine.
  - Meningococcal serogroup B.
- 2 months' follow-up after the initial vaccination
  - Pneumococcal polysaccharide vaccine (PPSV23).
  - Meningococcal conjugate vaccine.
  - Meningococcal serogroup B (>1 month after first dose).

Despite these recommendations, controversy exists regarding the true immune function of the spleen after embolization and the need for immunizations [8–14]. In this chapter, we discuss the necessity of vaccination prophylaxis in patients undergoing splenic embolization.

Search Strategy

Our search strategy was to use the terms ((splenic embolization) AND trauma) AND (function) on the Pubmed database. Limits were placed to include clinical trials, randomized controlled trials, multicenter studies published in the last 15 years to assess the immune function of the spleen after embolization. The search terms included medical subject headings (MeSH) and synonyms and these are outlined with the Population, Intervention, Comparator, and Outcomes (PICO) model in Table 11.1.

Table 11.1 Search terms and search strategy

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients undergoing splenic embolization after blunt injury	Need for vaccinations	No need for vaccinations	Infectious complications, mortality, immune function, functionality of the spleen
((("spleen"[MeSH Terms] OR "spleen"[All Fields] OR "splenic"[All Fields]) AND ("embolization, therapeutic"[MeSH Terms] OR ("embolization"[All Fields] AND "therapeutic"[All Fields]) OR "therapeutic embolization"[All Fields] OR "embolization"[All Fields])) AND ("injuries"[Subheading] OR "injuries"[All Fields] OR "trauma"[All Fields] OR "wounds and injuries"[MeSH Terms] OR ("wounds"[All Fields] AND "injuries"[All Fields]) OR "wounds and injuries"[All Fields]))			("physiology"[Subheading] OR "physiology"[All Fields] OR "function"[All Fields] OR "physiology"[MeSH Terms] OR "function"[All Fields])

Results

Several studies (Table 11.2) have evaluated immune function following splenic arterial embolization (SAE). None of the differences observed in immune function comparing patients undergoing SAE relative to healthy controls were statistically significant. Overall, based on data from available studies, there is marginal if any significant impact on splenic function when patients undergo SAE and it is therefore generally suggested by the authors of these studies that routine vaccination post-SAE is likely not necessary.

Relative to healthy controls (HC), the nonsignificant differences observed in immune function among those undergoing SAE in the various studies include reduced endotoxin responses of peripheral mononuclear cells within the first 1–7 days (by day 7 the response was similar to HC), lower splenic volumes in 17.6% of SAE patients (3 of 17 patients), lower IgM levels (91 vs. 110 mg/dL, normal 46–304 mg/dL), lower IgM memory B cells as a percentage of total B cells (7.55–9.97 SAE group versus 10.75 in HC), lower median vaccine antibody response following vaccination with pneumococcal-23 valent vaccine (3.97 in the SAE group; 2 patients with minimal response; IgG antibody level <2 compared to 5.29 in HC), lower CD27+/CD19+ (% of B lymphocytes, 11.7 vs. 15.5), lower IgM+/CD27+/CD19+ (% of B lymphocytes, 10.4 vs. 13.7), lower CD8 T lymphocytes (% all leukocytes, 6.3 vs. 8.5), and lower T lymphocytes % (% all leukocytes, 17.2 vs. 20.4). [11, 13–17]

A few studies evaluated differences in immune function following proximal versus distal SAE. Otloff et al. found that among those undergoing proximal SAE ($n = 5$), 2 patients had an insufficient response to the 23-valent pneumococcal vaccine while none of the patients in the distal SAE group ($n = 7$) showed a lack of response post-vaccination [13]. Another study found that distal SAE ($n = 11$) was associated with higher IgM memory B cells compared to proximal ($n = 38$) (9.97 vs. 7.55, not statistically significant) [14]. Authors conclude that distal SAE may be associated with better immune function compared to proximal; however, the limited sample size precludes definitive assessment.

It is important to note several limitations with the available data based on studies reviewed. There is no recognized standard for evaluating immune function following splenectomy or SAE and the studies used varying methods for assessing immune function. These studies are primarily observational in nature involving the identification of patients undergoing SAE for splenic injury and conducting laboratory or imaging assessments to determine whether splenic function and anatomy remained intact or unchanged following the procedure. The sample sizes for all of the reviewed studies were limited, all with <50 patients in the SAE group. And last, the follow-up period or duration of time between assessment and SAE varies according to study and is not consistently reported.

Table 11.2 Evidence on the need for immunizations after splenic artery embolization following trauma

Study	Patients	Outcomes assessed	Recommendations	Grade of evidence
Bessoud et al., 2007	*N* = 24 SAE (proximal)	Presence of HJB Serum antibody titers (pneumococcus and *Haemophilus influenzae B*) Ultrasound-Doppler splenic study	SAE (proximal) did not have a long-term impact on splenic anatomy or immune function	Low
Falimirski et al., 2007	*N* = 19 nonoperatively managed splenic injury *N* = 14SPL *N* = 15 HC	Red blood cell pit test and IgM level	Splenic injuries managed nonoperatively remained immunocompetent	Low
Nakae et al., 2009	*N* = 34 preservation treatment (PT) Includes SAE, splenorrhaphy, partial SPL *N* = 24SPL	Long-term prognosis, immunologic function, volume of spleen assessed through abdominal CT imaging Immunologic function assessment included measurement of: Complete blood count, HJB, immunoglobulins, lymphocyte subsets, and specific antibodies against 14 serotypes of *S. pneumoniae*	Prophylactic measures and close follow-up is necessary for PT and SPL patients	Low
Tominaga et al., 2009	*N* = 17 SAE *N* = 9 SPL *N* = 10 HC	Clinical examination, medical survey, blood sampling, nuclear medicine spleen scans IgM, IgG, C3 complement, complement factor B, CD3, CD4), CD8, complete blood count, HIV status	Immunization following SAE may not be necessary	Low
Malhotra et al., 2010	*N* = 8 SAE *N* = 4 SPL *N* = 4 HC	Immunocompetence of the spleen measured through T-cell subset analysis	Splenic immune function is preserved in SAE patients	Low
Shih et al., 2010	*N* = 5 SAE *N* = 11, non-SAE; nonoperative management *N* = undefined HC	Nuclear factor (NF)-kB translocations, phosphorylated I-kB expressions, and in vitro tumor necrosis factor (TNF)-alpha levels were assayed after endotoxin stimulation	SAE may alter immune response resulting in increased susceptibility to infections in patients with splenic injury	Low

Table 11.2 (continued)

Study	Patients	Outcomes assessed	Recommendations	Grade of evidence
Skattum et al., 2012	*N* = 15 SAE *N* = 14 SPL *N* = 29 HC	General blood counts Immunoglobulin quantifications Flow cytometric analysis of lymphocyte phenotypes Assessment of HJB Abdominal Doppler and contrast-enhanced ultrasound (CEUS)	SAE has only a minor impact on splenic function. Immunization probably is unnecessary	Low
Pirasteh et al., [18]	*N* = 34 SAE	Complete blood count with smear to determine presence or absence of HJB	Phagocytic function of the spleen is preserved following SAE	Low
Walusimbi et al., [19]	*N* = 11 SAE *N* = 21 SPL *N* = 20 HC	Serum total T lymphocytes (CD3), total B lymphocytes (CD19), helper T cells (CD4), suppressor T cells (CD8), natural killer T cells (NK), serum complement (C3, C4), and properdin factor B levels	SAE did not appear to impair systemic immune function relative to HC	Low
Olthof et al., 2014	*N* = 5 proximal SAE *N* = 7 distal SAE *N* = 8 SPL *N* = 10 HC	Antibody response to polysaccharide antigens (pneumococcal 23-valent polysaccharide vaccine) B cell subsets Presence of HJB	The splenic immune function following SAE was preserved; routine vaccination appears to not be indicated	Low
Skattum et al., 2014	*N* = 11 SAE *N* = 11 HC	General blood counts Immunoglobulin quantifications Flowcytometric analysis of lymphocyte phenotype Assessment of HJB Abdominal ultrasound	Mandatory immunization does not appear to be warranted	Low
Foley et al., 2015	*N* = 38 SAE (proximal) *N* = 11 SAE (distal) *N* = undefined HC *N* = undefined SPL	CT imaging to assess splenic volume IgM memory B cells	SAE is less likely to cause immunological complications compared to SPL Distal embolization may maintain better function	Low

Key: SAE: Splenic artery embolization; HC: Healthy control; SPL: Splenectomy; HJB: Howell–Jolly Bodies

Recommendations

- Due to variability in available evidence, low quality of studies, the inability to effectively test the immune function of the spleen following SAE, and the lack of a standard means of evaluating splenic function post-SAE, we recommend that all patients who undergo splenic embolization due to trauma receive vaccinations. (Evidence quality low; weak recommendation).

A Personal Approach to the Data

It is our personal approach that all patients undergoing splenic artery embolization following traumatic splenic injuries receive vaccinations according to ACIP recommendations, as referenced above. We believe the potential benefits of vaccination in this patient population outweigh the potential risk of developing a life-threatening OPSI following SAE.

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Part IV

Trauma Imaging

The Trauma Pan-Scan: Who Benefits from Immediate Whole-Body Imaging?

12

Lea Hoefer and Jennifer Cone

Introduction

Traditional ATLS teachings recommend an initial trauma imaging workup of a chest X-ray, FAST examination, selective radiographs, and CT scanning based on physical examination findings [1]. As imaging technology has improved, "whole-body CT" scanning (WBCT), or "pan-scanning" has become a viable and often used alternative for imaging multisystem trauma patients upon initial evaluation. This type of imaging, which includes the head, chest, abdomen, pelvis, and the entire spine including the neck, has been primarily used in patients who have undergone blunt trauma.

WBCT has the potential to identify injuries that might otherwise be missed on initial workup and expedite management of these injuries, which proponents argue leads to decreased morbidity and mortality. However, downsides remain, as there is a risk of over-diagnosis of non-clinically significant findings, potential for increased cost, and increased radiation exposure to patients.

Over the past 20 years, the body of literature on outcomes after WBCT versus selective imaging has grown, attempting to provide a definitive answer as to whether all patients with high and/or low-velocity blunt trauma should undergo a whole-body CT scan upon presentation to the emergency department. In this chapter, we will address this question by examining the currently available evidence and providing a more personal view of the topic informed by daily clinical practice.

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Search Strategy

The PubMed database from the National Library of Medicine was queried for the following search terms: “(trauma) AND ("whole-body CT" OR "whole body computed tomography" OR "whole body imaging" OR "pan scan")”. After filtering for the years 2000–2020 and English language articles, 503 papers were reviewed. Paper titles and abstracts were screened for relevance. Papers examining primarily pediatric populations, non-systematic reviews, and comments or letters to the editor were discarded. In total, 40 relevant studies were examined in depth: 8 systematic reviews and meta-analyses, 1 randomized controlled trial written in 2 separate papers, 3 prospective observational studies, and 27 retrospective cohort reviews.

Although not part of our search strategy, all papers reviewed examined patients sustaining blunt trauma. Penetrating trauma, by nature of disease process, has a different workup method. The dilemma, then, is what is the appropriate workup strategy for patients sustaining blunt trauma? How selective should a physician be when considering imaging? Traditionally, CT scans were ordered piecemeal, depending on the physical examination or complaints of the patient. However, in recent years, there has been a shift in practice towards pan-scan or whole-body CT scan. Do either of these options have an effect on mortality, complications, missed injuries, cost, or length of stay? There is, thankfully, a reasonable amount of data to guide our decision-making.

Patients sustaining blunt trauma via a low-velocity mechanism, like a fall from standing, versus a high-velocity mechanism, like a roll-over motor vehicle collision, may not require the same diagnostic algorithm. Additionally, a patient’s stability often factors into the workup decision making. In examining the literature, we have sought evidence that will help to better define the appropriate workup for these different patient populations (Table 12.1).

Results

Overall Survival

Despite its frequency in clinical practice, there is a relative scarcity of high-quality data regarding whole-body CT scans. First published in 2016, the REACT-2 trial is

Table 12.1 PICO table for whole-body CT scan

Population	Intervention	Comparison	Outcomes
Adult blunt trauma patients Mechanism: – Low velocity – High velocity Stability: – Stable – Unstable	Whole-body CT	Selective imaging	– Overall survival – Complications – Cost – Length of stay

Table 12.2 Randomized controlled trials

Randomized controlled trials					
Study author, Year	Patients	Survival (WBCT compared to selective imaging)	Additional findings	Cost/length of stay	Comments
Treskes, 2017 [20]	1083	Results published in 2016 paper	WBCT identified more clinically relevant incidental major findings (may cause mortality) OR 2.85, 95% CI (1.337–6.077), and moderate findings (may cause morbidity) OR 1.42, 95% CI 1.088–1.854)	N/A	REACT-2 trial
Sierink, 2016 [2]	1083	No difference in overall in-hospital mortality—16% mortality in each group, $p = 0.92$, or in subgroup analysis of polytrauma patients (22% vs. 25%, $p = 0.46$) or TBI patients (38% vs. 44%, $p = 0.31$)	Significantly decreased time to diagnosis of life-threatening injuries with total-body CT scan, also true for polytrauma patients	No increase in costs noted for immediate WBCT	REACT-2 trial

the only randomized control trial to date examining the role of WBCT on mortality (Table 12.2). The trial, which randomized patients in a non-blinded fashion to either WBCT or selective scanning using subjective inclusion criteria, found no difference in in-hospital mortality (16% vs. 16%, respectively, $p = 0.92$) as well as 24-h mortality (8% vs. 6%, respectively, $p = 0.23$) and 30-day mortality (16% vs. 17%, respectively, $p = 0.69$). The paper can be criticized, however, on multiple fronts. 22.8% of randomized patients were excluded post-randomization, introducing the possibility of bias into the results. Further, the inclusion criteria were subjective and there was a high degree of crossover from the treatment arm to the control arm. In total, 46% of the selective scanning group ended up receiving WBCT [2]. These criticisms may point toward a global trend that the sickest blunt trauma patients are all pan-scanned. When appropriately used, WBCT may serve as a mortality equalizer.

Although the REACT-2 trial and some of the earliest meta-analyses did not find any difference in survival between WBCT and selective imaging cohorts, multiple recent meta-analyses of large patient cohorts have demonstrated an overall survival benefit with WBCT [2–9]. Odds ratios ranged from 0.66 to 0.79 among the meta-analyses, demonstrating a reduction in mortality (Table 12.3). Among the remaining studies, there was a trend toward survival benefit with WBCT, although statistical significance was not reached (Table 12.3).

Table 12.3 Systematic reviews and meta-analyses

Systematic reviews and meta-analyses						
Study author, Year	Type of study/quality of evidence	Patients	Survival (WBCT compared to selective imaging)	Additional findings	Cost/length of stay	Comments
Arruzza, 2020 [12]	Meta-analysis	63,539 (12 studies in quantitative analysis)	No significant difference (OR = 0.854, CI = 0.715–1.021, $p = 0.083$)	Decreased time in ED (pooled SMD = −0.709, CI −1.198 to −0.220, $p = 0.004$)	No difference in ICU stay (SMD = 0.0801, CI −0.131 to 0.291, $p = 0.457$), hospital LOS (SMD = 0.0815, CI −0.180 to 0.343, $p = 0.541$)	Noted longer ventilation times and increased radiation dose in WBCT group
Chidambaran, 2017 [4]	Meta-analysis	32,307 (11 studies)	Decrease in overall mortality (OR = 0.79; 95% CI 0.74,0.83, $p < 0.05$), decrease in 24 h mortality (OR = 0.72, 95% CI 0.66,0.79, $p < 0.05$)	Decreased time in ED (pooled mean = −14.81; 95% CI −17.02, −12.60, $p < 0.00001$)	ICU LOS increase (pooled mean = 1.97; 95% CI 1.59, 2.34, $p < 0.05$), hospital LOS increase (pooled mean = 1.03; 95% CI 0.25,1.81, $p = 0.03$), decreased ventilator days (pooled mean = −2.01; 95% CI −2.41, −1.62, $p < 0.05$)	ISS higher for WBCT group in 10/11 studies examined
Hajibandeh, 2015 [5]	Systematic review	9 studies	Decrease in overall mortality (OR = 0.69 (95% CI 0.56–0.84), $P = 0.0003$)	Found decreased standard mean rate of mortality based on TRISS and RISC for WBCT group	N/A	N/A
Jiang, 2014 [6]	Meta-analysis	26,371 (11 studies)	Decrease in overall mortality (OR 0.66, 95% CI: 0.52 to 0.85; $P = 0.001$)	Decreased ED time (WMD = −27.58 min; 95% CI: −43.04 to −12.12; $P = 0.0005$)	No difference in ICU stay (WMD = 0.95 days, 95% CI: −0.08 to 1.98, $P = 0.07$) or hospital LOS (WMD, 0.56 days, 95% CI: −0.03 to 1.15; $P = 0.06$), significant decrease in ventilator days (WMD = 0.96 days (95% CI: 0.32 to 1.61, $P = 0.003$)	ISS higher in WBCT patients

Caputo, 2014 [3]	Meta-analysis	25,782 (7 studies)	Decrease in overall mortality (OR, 0.75; 95% CI, 0.7–0.79)	N/A	N/A	ISS higher in WBCT patients (29.7 vs. 26.4, $p < 0.001$)
Surendran, 2014 [7]	Systematic review	8 studies	Four studies with decreased mortality, some based on subgroup analysis. Two studies with no difference	Three studies demonstrated decreased ED times, two studies with decreased time to diagnosis or to OR	N/A	N/A
Sierink, 2012 [8]	Meta-analysis	5470 patients (4 studies)	No difference in overall mortality (odds ratio 0.91, 95% CI 0.79–1.05)	Two studies in analysis demonstrated lower ED times—No pooled analysis	N/A	N/A
van Vugt, 2012 [9]	Systematic review	9 studies	No differences in overall mortality in 3 studies, one study with improved mortality in severely injured patients	Four studies describe changes in treatment—rates 2–27% Five studies w/decreased ED time	N/A	N/A

Only one of the systematic reviews, Hajibandeh et al., assessed the WBCT and selective imaging groups for observed versus predicted mortality using two injury scoring systems—TRISS (Trauma and Injury Severity Score) and RISC (Revised Injury Severity Classification). Their analyses demonstrated a reduction in standardized mortality ratio (SMR) of 0.80 (95% CI 0.74–0.87) based on TRISS scoring, and 0.85 (95% CI 0.81–0.89) based on RISC in the group that underwent WBCT. This reduction in SMR was not found in the group that underwent selective imaging [5]. Thus, WBCT likely has some degree of beneficial effect on mortality.

Decreased Time to Care

One of the ways in which WBCT is thought to be able to improve care for blunt trauma patients is by decreasing the time it takes to identify injuries and provide definitive management. Multiple meta-analyses found decreased time spent in the ED/trauma bay in their pooled analyses, and additional systematic reviews commented on similar findings in the studies included in their results [4, 6–10]. Reductions in ED time among studies performing pooled analysis found average decreased times ranging from 14 to 27 min. Impressively, one prospective observational trial showed a wait time decrease of 68 min in their study [11] (Table 12.4).

The one randomized control trial examining WBCT, the REACT-2 trial, found a statistically significant decrease in time to diagnosis of life-threatening injuries among patients in the WBCT arm [2]. The median time to diagnosis was 50 min for patients who underwent WBCT and 58 min for the selective imaging groups ($p = 0.001$) [2]. Reducing the time it takes to work up a patient in the ED, including diagnosing and creating treatment plans for injuries, not only helps patients reach definitive care much quicker, but also likely improves the efficiency of care in busy trauma centers.

Impact of WBCT on Cost and Length of Stay

Despite multiple studies examining the effects of WBCT on trauma care, there is not a clear trend in the literature regarding the effect of WBCT on overall hospital cost, the overall length of stay (LOS), or ICU length of stay.

Only two studies mentioned the effect of WBCT on cost. The REACT-2 trial showed no increase in costs for the group that underwent WBCT scan (24,967 € vs. 26,996 €, $p = 0.44$) [2]. Conversely, the prospective observational trial by James et al. found an increased total hospital cost of nearly $5000 with the use of WBCT, a finding that was statistically significant ($p = 0.01$) [10]. Yet, this same study found that the total radiology cost was actually $50 cheaper with WBCT ($p = 0.629$) but the total cost of CT was only $54 more in the WBCT group ($p < 0.0001$) [10]. These conflicting results suggest that the current studies are likely underpowered to provide a real answer.

The meta-analysis performed by Chidambaram et al. suggested an increase in ICU LOS (pooled mean difference 1.97 days, 95% CI 1.59–2.34, $p < 0.05$) and overall LOS (pooled mean different 1.03 days, 95% CI 0.25–1.81, $p = 0.03$) among

Table 12.4 Prospective observational trials

Prospective observational trials					
Study author, Year	Patients	Survival (WBCT compared to selective imaging)	Additional findings	Cost/length of stay	Comments
James, 2017 [10]	426 patients - 206 pan-scanned, 220 selectively scanned	No difference in mortality (8% vs. 4%, stats not reported)	Decreased missed injuries (0.5% vs. 3.2%, $p = 0.069$, 95% CI 0.82–55.3), increased rate of incidental findings (76.7% vs. 62.3%, $p = 0.002$, 95% CI 0.33–0.76)	No change in hospital LOS, decreased LOS in ER by 68.2 min ($p = 0.026$, 95% CI −134.4 to −2.1), increased total hospital cost by $4971 ($p = 0.01$)	N/A
Gupta, 2011 [21]	701 patients - 600 pan-scanned, 101 selectively scanned	N/A	Abnormality present in 22% of desired scans, 10% (102) of undesired scans. Critical action taken on 3 patients who had an undesired scan—0.3% of patients pan-scanned. 4 patients who had an undesired scan were admitted to the ICU	N/A	37% of subjects had ISS 1 or 2. 20% of subjects had ISS over 15
Salim, 2006 [22]	1000 patients with no external signs of abdominal injury—592 patients evaluable who were pan-scanned for high velocity mechanism, 408 unevaluable patients who were pan-scanned for depressed GCS	N/A	Clinically significant injuries found in 3.5% CT head, 5.1% CT c-spine, 19.6% CT chest, 7.1% CT abdomen. 7.9% of patients with a normal CXR had abnormality on chest CT. Treatment changed in 18.9% of patients with abnormal scans	N/A	N/A

patients who received WBCT compared to patients who underwent selective scanning [4]. This effect may be related to the same drivers of the increased injury severity score seen in WBCT patients—either additional injuries are identified leading to increased LOS, or patients who undergo WBCT are selected for a more complete workup based on more suspected severe injuries to begin with. Either of these scenarios would potentially lead to an increase in LOS. However, two other meta-analyses which also performed pooled analysis on these outcomes found no significant difference in either hospital or ICU length of stay [6, 12]. With no clear answer in the current literature, future studies investigating WBCT can provide useful information by clarifying the impact pan-scanning has on factors such as length of stay or treatment costs.

Injury Severity Score

It is worth noting the disparity in mean Injury Severity Score (ISS) between patients undergoing WBCT and those undergoing selective imaging. Several studies found that the average ISS tended to be higher amongst patients who received WBCT [3, 4, 6]. Among these three studies, Caputo et al. was the only group to perform a pooled analysis of ISS in WBCT versus selective imaging. Their analysis demonstrated a 3 point increase in ISS among patients who had undergone WBCT (29.72 vs. 26.46, respectively, $p < 0.001$) [3]. Neither Chidambaram et al. nor Jiang et al. performed a pooled analysis; however, both noted that 10/11 and 5/11 studies in their respective analyses found a statistically significant higher ISS in WBCT groups compared to selective scanning groups [4, 6].

On the whole, it is difficult to interpret the relationship between ISS and WBCT. There is likely selection bias present in much of the decision-making regarding a trauma workup. The majority of studies examining WBCT are retrospective studies, and it is difficult to determine to what degree patients with more severe appearing injuries were more likely to have undergone WBCT. The same bias is almost certainly present in the prospective observational studies. However, WBCT itself may lead to a higher ISS as the pan-scan may identify additional injuries compared to selective scanning. Future randomized control trials may clarify the relationship seen between WBCT and ISS by decreasing the effects of selection bias.

Low-Velocity Blunt Trauma

The majority of studies and meta-analyses to date have focused on patients with "major blunt trauma" and higher injury severity scores. However, there are a group of studies examining the use of WBCT in elderly patients who sustained low-velocity blunt trauma, mainly falls from standing [13–16]. Although these were all

retrospective reviews and provide a lower quality of evidence, they do provide us with some guidance on the utility of WBCT in patients with low-velocity trauma. In general, the authors of these studies have concluded that there was little benefit to performing whole-body CT in these patients.

In their 2013 study, Dwyer et al. found no mortality benefit when elderly patients sustaining ground level falls underwent WBCT (p = 0.74, OR 0.97, 95% CI 0.80–1.18) [13]. Two other studies by Kim et al. and Lepkowsky et al. did not examine mortality but instead focused on changes in management. Kim et al. found a 63% rate of new findings in their study, but only a quarter of these findings led to a change in management with even fewer patients (2%) undergoing a procedure or operation based on these new findings [14]. Additionally, the authors noted that most of the patients who ultimately required a change in management demonstrated symptoms or examination findings that could have been used to dictate a selective scanning approach. Lepowsky et al. found an even lower rate of change in management based on WBCT findings (<12%) [15]. When looking specifically at the abdominal portion of the WBCT among elderly patients with a fall and rib, pelvic, or thoracolumbar fractures, Gartin et al. found that only 0.9% of patients had an intra-abdominal injury identified on their pan scan [16]. In patients with no abdominal pain and a negative FAST exam, only 0.3% of patients that had an intra-abdominal finding. These results suggest that WBCT in patients who sustain a low-velocity mechanism was low yield [16].

Hemodynamic Stability

Traditionally, only patients with a relatively stable blood pressure would undergo a CT scan. Unstable patients often are managed in the trauma bay or taken to the operating room for exploration. However, as trauma centers become more aggressive, traditional practice is questioned. There appears to be evidence that unstable blunt trauma patients may benefit from immediate WBCT. Two retrospective studies looking at outcomes specifically in patients with severe blunt trauma and signs of instability found decreased mortality among the group undergoing WBCT [17, 18]. A retrospective review of the Japanese national database examining over 40,000 patients with at least one abnormal vital sign found a decreased mortality rate amongst the 19,766 patients who underwent WBCT (OR 0.84, 95% CI 0.72–0.98) [17]. The 2013 German multicenter cohort study performed by Huber-Wagner et al. examined over 16,000 patients and performed subgroup analyses on patients with moderate (SBP 90–110 mmHg) or severe (SPB <90 mmHg) shock. Decreased mortality was observed among patients undergoing WBCT in both of these groups—18.1% in WBCT compared to 22.6% for patients with moderate shock ($p < 0.001$) and 42.1% in WBCT versus 54.9% among patients with severe shock ($p < 0.001$) [18]. Despite the size of these retrospective cohorts, more high-quality data is needed to elicit a clear benefit for unstable patients.

Recommendations Based on Data

In the one randomized control trial and eight systematic reviews and meta-analyses based on retrospective cohort studies currently published, there is mixed data regarding mortality benefit from whole-body CT. Five of the eight systematic reviews and meta-analyses show decreased mortality when patients undergo a trauma pan-scan. The remainder of the studies shows no difference in mortality. Importantly, no study shows increased mortality with WBCT. There is minimal data specifically looking at high versus low-velocity mechanisms, however, many of the reviewed studies only include patients sustaining high-velocity trauma. There is likely a degree of bias in the data, as patients who undergo WBCT have higher ISS scores than patients that undergo selective scanning.

Overall, there seems to be agreement that WBCT decreases the time to diagnosis of injuries, thereby decreasing the time spent in the emergency room and trauma bay. There is no consistency, however, on the effect WBCT has on total hospital cost, total hospital stay, and ICU length of stay.

In the above literature review, there is no data suggesting a negative consequence to WBCT, while there seems to be a mortality benefit, improved emergency room throughput, and faster time to diagnosis. The paucity of high-quality data on patients with a low-velocity mechanism or instability precludes a recommendation. Thus, patients sustaining a high-velocity blunt trauma mechanism should undergo an immediate whole-body CT scan.

Summary of Recommendations

- Patients sustaining a high-velocity blunt trauma mechanism should undergo an immediate whole-body CT scan (*evidence quality moderate, strong recommendation*).
- Cannot make a recommendation on immediate whole-body CT scan for patients sustaining a low-velocity blunt trauma (*evidence quality low; moderate recommendation*).
- Cannot make a recommendation on immediate whole-body CT scan for unstable patients (*evidence quality low; weak recommendation*).

Personal View of Data

While there is not a complete agreement of the data, we believe that there is enough information to point us in the right direction. At our institution, patients that sustain a high-velocity mechanism, such as a high-speed motor vehicle collision or a fall from a height of greater than 20 feet, all undergo an immediate whole-body CT scan. We do this for several reasons. First, the evidence suggests that there may be a mortality benefit to pan-scanning, and at a minimum, it finds additional injuries. Second, in our busy urban level 1 trauma center, pan-scanning allows a streamlined

approach to patient care, and avoids confusion or delays in the workup of the patient. Third, missing an injury is unacceptable from a quality or litigious perspective. We believe that immediate whole-body CT scan is the standard of care workup for patients sustaining high-velocity blunt trauma.

We believe that there is not conclusive literature to mandate a pan-scan in patients that sustain a low-velocity mechanism, such as assault or a fall from standing. In these patients, we tend to do selective scanning, based on the mechanism and clinical concern. There is some data to suggest that a normal physical examination, normal laboratories, and normal bedside tests of CXR and FAST examination are sensitive enough to rule out significant intra-abdominal injury [19]. This approach, however, does take more time and attention. Thus, during incredibly busy periods, the fallback often becomes immediate whole-body CT scan.

Further randomized control trials are needed to increase the quality of evidence in the literature. Additionally, future studies will ideally focus on differentiating the workup for high-velocity versus low-velocity blunt trauma and determining the feasibility and outcomes of pan-scanning unstable patients.

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Nonselective Arterial Embolization for Pelvic Fractures

13

David Graan and Zsolt J. Balogh

Introduction

Trauma is a leading cause of death in the young population [1]. Pelvic injuries and their associated hemorrhage pose a significant challenge for trauma surgeons. These fractures are present in up to 9.3% of patients with high-energy blunt trauma [2]. Due to the high energy mechanism, 90% of patients have associated injuries and 50% have other sources of hemorrhage [3]. The mortality rate in patients with any type of pelvic fracture is approximately 13.5–16% [2, 4]. This significantly rises to 32–60% in patients with pelvic fractures and hemodynamic instability [2, 5, 6] and although accounting for less than 10% of pelvic fractures presenting to level 1centers, they represent the bulk of the mortality in this group [7]. Pelvic fracture continues to carry the highest mortality rates of any skeletal injury with hemorrhage being the major reversible contribution to mortality [8] (Table 13.1).

Table 13.1 PICO table

Patients	Intervention	Comparator	Outcomes
Patients with pelvic fractures	Pelvic angioembolization	Selective vs. nonselective angioembolization	Complications, re-bleeds, death

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Arterial angioembolization (AAE) has been used more and more frequently to control pelvic-related bleeding since it was described in the literature in the 1970s by Margolies et al. [9]. AAE is shown to have a high success rate of 80–100% [10, 11] and is effective against arterial hemorrhage, which is the source of bleeding in about 15% of pelvic fracture associated hemorrhage but is uniformly present among life-threatening pelvic bleeders [7, 12]. AAE can be performed as a primary intervention or in secondarily stabilized patients with arterial contrast extravasation seen on CT.

Resuscitation, timely identification, and adequate treatment of pelvic hemorrhage and significant associated injuries are essential [13]. Unfortunately, the management algorithms in recent years have become so complex that they have limited use in practice with no gold standard guidelines or multicenter analysis established. Verbeek et al. [6] studied 11,109 major blunt trauma patients who were admitted to 11 Australian/New Zealand trauma centers between 2000 and 2003. Major pelvic fractures were seen in 1050 patients, of which 217 were hemodynamically unstable. Pelvic angiography was performed in 27% and showed an acute bleed in 74%.

All patients with suspected unstable pelvic fractures should be managed by a multidisciplinary team. Hemostatic resuscitation should begin early. Primary and secondary surveys follow the Advanced Trauma Life Support (ATLS) guidelines [14]. The main goals of initial management are to identify the pelvic fracture, achieve bleeding control, and to identify associated life-threatening extra-pelvic injuries. The hemodynamic response of that patient after initial resuscitative measures indicates the next step in management.

The interventions available for hemorrhage control in pelvic fractures are the application of a pelvic binder [15], surgical application of an external fixator [16], arterial angioembolization (AAE) [17], extraperitoneal pelvic packing [18], and retrograde endovascular balloon occlusion of the aorta [19].

Up to 76% of patients who have persistent hemodynamic instability despite resuscitation with blood products, pelvic compression, and exclusion of other sources of major bleeding will have arterial bleeding and should undergo angiography if immediately available [10, 20]. The recent Western Trauma Association update has outlined arterial angioembolization as the primary method of hemorrhagic control in patients resistant to fluid resuscitation and mechanical stabilization [21]. When time and logistics allow, CT is the gold standard in diagnosing arterial bleeding or looking for ongoing bleeding. If a blush is detected, the patient should be transported to the angiography suite.

Nonselective arterial embolization can be achieved in a timely fashion in either interventional radiology suites, in hybrid operating theaters, or REBOA technique in the resuscitation bay. Selective angioembolization requires skill, time, resources, and local protocols. In extrremis, for an unstable patient bleeding from a pelvic fracture, bilateral nonselective embolization of the internal iliac arteries could be considered.

This chapter will address the use of nonselective arterial embolization in the management of pelvic fractures and will review the anatomical considerations, technique, timing, patient selection, comparable outcomes between selective and nonselective embolization, complications, and clinical utility.

Results

Embolization is the deliberate blockage of a target vessel or territory to stop hemorrhage. A thorough knowledge of anatomy and its variants are essential before proceeding. Angiography for the control of hemorrhage has an important role in the treatment of pelvic fractures and is supported by the highest level of evidence. Pelvic angiography with embolization can be performed in a selective or nonselective manner, it can be performed bilaterally if needed and even repeated to control bleeding. Moore et al. [22] in 1987 performed surgical ligation of the internal iliac artery in four clinically unstable patients with blunt or penetrating trauma in which they successfully ceased pelvic bleeding, paving the way for the use of this technique to treat unstable patients.

Anatomic Considerations

Arterial bleeding has been reported in up to 10–15% of major pelvic fractures and it is uniformly present among hemodynamically unstable pelvic fractures. In this group, embolization saves lives and reduces the need for transfusions [12]. Although with hemostatic resuscitation the often-self-limited cancellous bone and venous bleeding are the most frequent sources of hemorrhage with pelvic fractures, arterial bleeding is the leading cause of life-threatening hemorrhagic shock in patients with pelvic trauma [23].

The landmark study by Huittinen et al. informed our early knowledge of patterns of bleeding in pelvic fracture. In 1973, Huittinen et al. [24] performed postmortem angiographies in 27 patients with pelvic fractures and found that extravasation results mostly from venous structures and fractured cancellous bone. They revealed only 11.1% of their patients exhibited arterial bleeding. Venous and cancellous bone bleeding was present in all pelvic fracture patients. The iliolumbar vein was noted to be disrupted in 60% of fractures; this pattern of venous hemorrhage is seen with fractures in the sacroiliac portion of the pelvis [25]. Venous pelvic bleeding does not however feature heavily in the literature. The proposed thought is venous bleeding occurs into the retroperitoneum, which is a closed space. Most bleeding occurs from small/medium veins that can stop naturally if the patients' cardiovascular function, blood volume, and coagulation profiles are kept within acceptable limits [3].

Anterior pelvic bleeding originates mainly from the internal pudendal (27%) and the obturator arteries (16%) [4]. Posterior bleeding occurs from the superior gluteal (25%) and the lateral sacral arteries (23%) [4]. Ligation of the internal iliac artery during laparotomy was previously used to control pelvic arterial hemorrhage. However, this method was proven ineffective because of the rich collateral blood supply to the pelvis [26].

Pelvic Ring

The pelvis is a ring structure made up of three bones: the sacrum and the two innominates. The ring is formed by the connection of the sacrum to the innominated bones at the sacroiliac joints at the back and the pubic symphysis in the front [27]. An important ligamentous complex also gives these joints strength and stability. The SI joints are the strongest in the body and resist both vertical and anterior-posterior displacement [28]. Anteriorly, the opposed bony surface of the pelvis is covered by hyaline cartilage and fibrous tissue. The pubic symphysis is the weakest link in the ring and supplies only 15% of the intrinsic pelvic stability. Significant disruption and displacement of one area of the pelvic ring is usually accompanied by a disruption in another and is usually the result of both bone and ligament disruption. It is well known that the volume of the pelvis increases with mechanically unstable pelvis fractures [29]. This increased volume is thought to decrease the tamponade effect of the retroperitoneal tissues and intrapelvic organs, leading to further bleeding. Baque et al. [25] demonstrated a 20% increase in pelvic volume with a 5-cm pubic diastasis using cadaver models. The absolute volume increase is still negligible in terms of blood loss even with the increase of 20%. In a closed pelvic ring, the venous bleeding from the low-pressure system cannot expand, but arterial bleeding can pose continued threat to life.

Pelvic Fracture Classification

The Tile fracture [30] and the Young–Burgess [31, 32] classifications are the two most common radiological classification systems used.

There is controversy about the clinical usefulness of both classification systems in determining the risk of significant bleeding and mortality [33, 34]. In the only study that compared the two, both classifications have similar predictive values for mortality, resuscitation fluid, and transfusion requirements [35]. Hussami et al. [33] found a significant correlation between the tile fracture type and arterial, but not venous bleeding. Agri et al. [13] found that significantly more patients with Tile C fractures underwent embolization for bleeding control. They also found Tile C fractures were associated with higher transfusion requirements and a higher mortality rate than Tile A or B fractures. Overall, published data shows only low to moderate interobserver reliability of both systems [36, 37].

Basing the decision to perform angiography on pelvic fracture type alone is not recommended. Force vectors and fracture patterns inconsistently predict those with arterial bleeding and the need for angiography. Exsanguinating hemorrhage can and does occur in all fracture patterns, even simple rami fractures in the elderly [11, 38, 39].

Use of Angioembolization

Contrast extravasation on a CT scan is highly predictive of active arterial bleeding with sensitivity and specificity values ranging between 66–90% and 85–98%, respectively [39, 40]. The exact hemorrhagic site can often be identified on CT which guides the time-critical AAE treatment by the interventional radiologist [41]. The absence of contrast extravasation on admission CT is an excellent screening test to exclude the presence of an active arterial hemorrhage and therefore the need for AAE, with negative predictive values over 98% [42]. An active bleeding site is identified as a high-density focus due to a leaking blush/jet of contrast seen on the arterial phase scan, with further pooling of the contrast on the Portal Venous scan. Any site of contrast extravasation or arterial injury should be embolized. While extravasation on CT indicates arterial injury, studies have shown that nearly half of the patients with contrast extravasation on CT did not require embolization as active bleeding was not identified on interventional radiography [43]. The discrepancy between CT and angiographic findings is thought to be due to vessel spasm, which may be secondary to local inflammatory responses generated by bleeding [44]. Therefore, it is imperative to consider proceeding to angiography and embolization urgently following a trauma scan if the clinical suspicion remains high.

The real prognostic question is if the patient can make it to a CT scan at all before embolization. Historically, a CT scan before AAE was not recommended due to the urgency of hemorrhage control in a critically bleeding patient. More recently, most resuscitation bays have rapid CT scans immediately adjacent and trauma patients are less likely to present in severe coagulopathy due to overzealous crystalloid resuscitation. These advances made it possible to have a new group of patients with CT scan before angiography and a selected smaller group of patients who are critical and still needs AAE immediately [45] (Fig. 13.1).

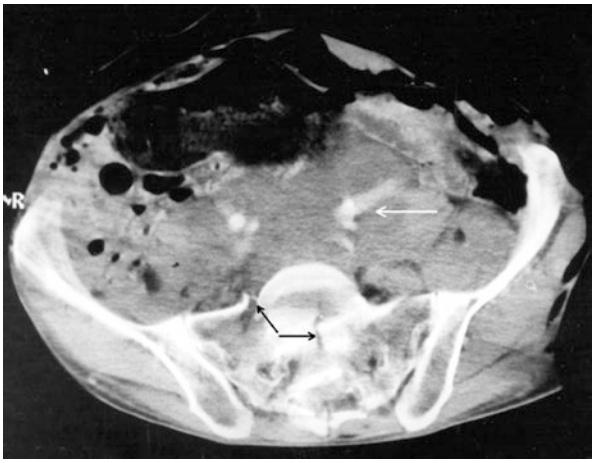

Fig. 13.1 Contrast-enhanced helical computed tomography of the pelvic region shows comminuted sacral fractures (black arrows) and contrast extravasation around the left iliac vessels (white arrow) surrounded by a large pelvic hematoma. Additional findings included pneumoretroperitoneum and subcutaneous emphysema secondary to bilateral pneumothorax

The use of angiography depends on several factors, including the patients' clinical scenario, vital signs and continued need for resuscitation, angiographer availability, and physician experience [46]. Lai et al. [47] identified three independent predictors of active arterial hemorrhage that can assist in patient selection for embolization. These predictors include contrast extravasation seen on CT (OR 74.6, $p < 0.001$), patients requiring more than 8 units of packed red blood cells (PRBC) (PR 12.5, $p = 0.018$), and injury severity score (ISS) $\geq$ 16 (OR 11.1, $p = 0.029$). Eastridge et al. [7] reported that 27 of 46 patients with both persistent hypotension and a severely unstable pelvic fracture indicate arterial bleeding. Using the patient's hemodynamic status and response to resuscitation in addition to the results of contrast-enhanced CT is helpful in predicting the need for angiography. Pelvic hematoma size can also inform patient selection for embolization. Blackmore et al. [48] found that hematomas >500 cm^3 had a significantly increased risk ratio of 4.8 for arterial injury at angiography. In the setting of major pelvic fracture, age >60 regardless of hemodynamic status is highly associated with the need for embolization (OR 15) [49]. The problem with many of these prediction models is that they include information that is not available at the time of the decision-making at the resuscitation bay (ISS score, 24-h transfusion rate, and size of pelvic hematoma). Toth et al. [50] prospectively utilized only the variables, which were available within 30 min of the arrival of the patient. The prediction model showed that patients who definitively required AAE had pelvic ring injury, negative FAST, metabolic acidosis with base deficit worse than −6, and no extra-pelvic sources of bleeding. It is hypothesized that the higher levels of bleeding in the elderly are due to atherosclerotic vessels and loose periosteum which leads to ineffective physiological hemostasis [47].

Arterial Angioembolization Technique

Most treatment algorithms undergo a dual-phase CTA (computed tomography angiogram) scan as first-line imaging in adults with suspected high energy pelvic fractures. The routine initial phase is taken at 20 s post contrast medium to obtain an arterial phase, followed by a 70-s portal venous phase [41]. Multiphase CT scans might not be feasible for critically ill trauma patients. These patients will usually undergo a single-phase contrast-enhanced CT with portal venous phase imaging after a 70-s delay from initiation of contrast medium.

The angiography suite should be prepared as a mini-intensive care setting [51]. The equipment required for the angiography include fluoroscopy, power injectors, vascular access sheaths, guidewires, catheters, and intravenous access.

Regarding the angiography procedure itself, most authors describe a standard approach via the common femoral artery (CFA). Under local anesthetic, the CFA is punctured with a micro-puncture needle set or a 4 or 5 French sheath which is introduced at the level of the midpoint of the femoral head to access the arterial tree. In some patients, access to the femoral artery can be difficult due to obesity, hematoma, hypotension, or degloving injuries [20]. An aortogram is then performed to

delineate the anatomy. Then guided by the CT findings, a direct catheterization of the suspected internal iliac is performed. Contrast is then infiltrated to identify the bleeding point, noted by contrast blush or extravasation. Digital subtraction angiography (DSA) is used to guide the operator along with the arterial map. Most modern angiography units use pulsed fluoroscopy where radiation is produced in a pulsating fashion instead of a continuous beam. The primary advantage of pulsed fluoroscopy is the significant reduction in radiation dose [27]. Standard catheters are used however, if the bleeding point is not evident, further selective micro-catheterization and angiogram of the pelvic arterial branches on the affected side may be necessary. Once this is evident, the bleeding artery is embolized using embolic materials.

Various embolic agents are available, they can be broadly divided into temporary or permanent. They are then further divided into mechanical occlusions, particulate agents, and liquid agents. Gelfoam and coils seem to be the most commonly used materials either as a single agent or in combination. Gelfoam is a biodegradable gelatine sponge, which can be cut to size and mixed with contrast and normal saline prior to delivery. It remains the most popular choice as it is temporary lasting 7–21 days, relatively easy to use, quick, economical, and has relative independence from coagulation [52, 53]. Scatter embolization of multiple distal smaller branches can be achieved with gel foam suspension mixed with contrast providing temporary occlusion. Gel foam/contrast mix is injected under direct visualization until flow in the vessel ceases or is markedly diminished.

Coils should be used for nonselective embolization of main arteries and larger branches. They allow for very precise positioning. Metallic coils come in various sizes and are coated with thrombogenic material (fibrogenic fibers) or are uncovered. They work by damage to the intima and provide a large thrombogenic surface and mechanical obstruction of the lumen. They allow rapid mechanical occlusion of the vessel as they are injected through the microcatheter. Several coils are usually required to conform into an occlusive coil ball which creates a scaffold for thrombosis [54]. The downsides to this technique are that extensive coil usage precludes distal access in cases of rebleed and that their efficacy depends on the patient's coagulation as clot needs to be formed in the coils before hemostasis is achieved. Thus, in the presence of coagulopathy which is common in trauma patients, a combination of coil placement followed by injection of gel foam can be very useful. Liquid agents such as glue or Onyx may be considered for very distal vessels and can be used in the cases of re-bleeding.

After vessel embolization, the potential collateral vessels should be evaluated to identify additional supply. Completion angiography should be undertaken to document the cessation of bleeding.

Timing of Arterial Angioembolization

Delay to embolization is associated with significant increases in mortality. Tanizaki et al. [55] found mortality rates of 16% with embolization within 60 min compared to 64% when delayed. Additionally, Balogh et al. [56] described their protocol of

pelvic angiography within 90 min of admission improved mortality. Hemodynamically unstable patients had a median time interval from ED arrival to AAE that was 10 min shorter for survivors than nonsurvivors, but not statistically significant due to the smaller sample size. Agolini et al. [10] reported a mortality increase from 36 to 75% if embolization was delayed beyond 3 h of admission. Evers et al. [26] reported a high mortality rate, relating to its long mean time to embolization (>4 h) which can lead to a prolonged flow state, multisystem organ failure, and sepsis. In a multicenter Australian Study delay to angiography when used as the primary treatment modality was common, only 15% of embolization occurred within 90 min of arrival [6]. Time intervals from ED arrival to AAE found in the literature vary, with a median time of 280 min in one recent study from a high-volume trauma center [57]. The availability in different centers to IR plays a crucial role, especially after hours. Angiography and embolization itself can be time-consuming. The overall time for performing embolization has been reported from 50 min to 5.5 h [10, 20].

More recently, some institutions started to promote preperitoneal packing (PPP) again due to no timely access to AAE and consistently reporting that around 15% of the PPP patients still need AAE later [58, 59]. We believe these are the patients who would need timely AAE in the first place. Generally, AAE as a lifesaving hemorrhage control measure should be performed with the same urgency as trauma laparotomy or thoracotomy to stop bleeding.

A recent prospective analysis from a high-volume level 1 trauma center analyzed all pelvic fractures over a 10-year period between 2009 and 2018 [45]. They found that over this time period, the time to AAE did not improve even though mortality rates remained low (14%, of which none were related to exsanguination). Overall, timely embolization is critical and reduces mortality. The patient should have immediate treatment as per the local guidelines and protocols, such as Resuscitative Endovascular Balloon Occlusion of the aorta (REBOA) in the emergency department, embolization in the interventional radiology department or be taken to a hybrid operating room.

Selective Versus Nonselective Angioembolization Indications

Angiography for pelvic fractures allows for both selective embolizations of bleeding arteries and nonselective embolization of bilateral internal iliac arteries.

A critically bleeding, non-responding unstable patient with a pelvic fracture is a typical indication for nonselective embolization of both internal iliac arteries. The indication for nonselective embolization is usually an angiogram showing multiple bleeding arteries, or a high suspicion of multiple vessel injury in a patient with substantial hemodynamic instability. Occasionally, when there are multiple distal bleeding sites, the operator may choose to perform proximal or nonselective embolization using temporary embolic materials to save valuable time in hemodynamically unstable patients [41]. Nonselective bilateral embolization of the entire Internal iliac system should be a last resort for severe bleeding. Clinical instability

or worsening in the angiography suite may also influence nonselective angiography. Due to the generous collateral pathways and anastomoses between each artery and cross circulation to the other side, bilateral embolization at their common trunk is required in order to stop truly significant bleeding [51, 59, 60].

In most clinical situations, operators may attempt more selective embolization. This is often in hemodynamically stable patients or patients who have responded to initial fluid resuscitation. Selective embolization is used when an active source of bleeding is identified. The most commonly reported vessels for selective embolization in decreasing order are the internal iliac artery (67.2%), unnamed branches of the internal iliac (17%), the superior gluteal artery (4.4%), the obturator artery (4.1%), and the internal pudendal artery (3.2%) [61]. Super-selective embolization, which often requires the use of 2–3 Fr micro-catheters through a coaxial system is technically more difficult and therefore time-consuming and has a higher incidence of pelvic arterial hemorrhage [62]. Fang et al. [62] demonstrated that recurrent pelvic bleeding also seems to be more common after selective embolization than after nonselective embolization, suggesting this practice should be limited.

Complications

The etiology of complications after angioembolization is a mixed scenario involving both the direct effects of embolization and the results of the often-substantial initial trauma [63]. Although AAE is considered to be a safe procedure that can stem uncontrolled bleeding, there are reports of complications in the literature [51]. The rates vary substantially from 0 to 63% [61].

Puncture site hematoma due to poor closure may lead to the pseudo-aneurysm formation or groin hematoma, femoral artery thrombosis, or subintimal dissection [51, 52]. Cases of gluteal necrosis associated with embolization seem to be related to primary trauma along with protracted hypotension rather than a direct complication of AAE [64]. Other complications such as bladder, femoral head, distal colon, and ureter and skin necrosis have been described [59, 65]. Travis et al. [66] described paresis, impotence, and surgical wound compromise. Ramirez et al. [67], however, examined sexual dysfunction in males undergoing bilateral internal iliac embolization and found no difference compared with case-matched pelvic fracture patients not undergoing embolization, suggesting that when it does occur, it may be due to the injury.

Travis et al. [66] also compared complications between selective and nonselective AAE and found no statistical difference in complications, this finding is also corroborated by the multicenter study by Hymel et al. [63]. The nonselective embolization group, however, had a significantly increased rate of thromboembolic complications (12.1 vs. 0%). The lack of discrepancy in complications between both groups is likely due to the rich collateral arterial supply within the pelvis.

Radiation exposure is an important consideration, the dose in a single pelvic embolization procedure is reported to be as much as 3Gy [68]. The incidence of allergic reaction to contrast materials range from 3 to 13% [69]. Furthermore,

unnecessary use of contrast should be avoided, as trauma patients are prone to developing contrast-induced nephropathy [70].

Pelvic re-bleeding can occur following initial angiography and embolization, re-bleeding may occur up to a rate of 9.7% [40]. Authors have [62, 71] identified hypotension, pre-procedural hemoglobin of <7.5 mg/dl, pubic symphysis disruption, absence of concomitant intra-abdominal visceral injury, a transfusion rate >2 U of blood per hour, and the presence of two or more pelvic arterial injuries on initial angiogram as statistically significant predictors of recurrent arterial hemorrhage. Alternatively, post initial angioembolization, rebleed has been linked with dislodgement of the embolization material, post-procedural transfusion requirement of >6 units PRBC, continued hemodynamic instability, super-selective embolization, and a persistent base deficit [28, 62, 71]. No-selective AAE should be used in the treatment of a rebleed.

Overall, the high success rates and potentially lifesaving effect of emergent non-selective embolization outweigh the marginal and uncertain risks of complications of the procedure.

Recommendations Based Upon the Data

Pelvic hemorrhage from fractures after blunt trauma has a high mortality and continues to represent the most frequent source of preventable death following blunt trauma. Even in the face of improved diagnostic and therapeutic techniques, the mortality rate for this population remains high. There are three major sources of bleeding from pelvic fractures. The management of each of these bleeding sites would ideally be specific. Critically bleeding patients with properly bound pelvis not responding to hemostatic resuscitation have arterial bleeders. Treatment options include pre-hospital or early pelvic binding, fracture stabilization with external fixation, intraoperative peritoneal packing, and angiographic embolization.

The patient's clinical condition is the most important consideration in deciding between surgical versus endovascular intervention. Rapid diagnosis of potential trauma hemorrhage via radiography and FAST is critical in the early assessment of hemodynamically unstable patients. CT has now become the standard investigation to identify solid organ, mesenteric, pelvic, and retroperitoneal bleeding [27]. Toth et al. [50] prospectively utilized only the variables, which were available within 30 min of the arrival of the patient. The prospective prediction model showed that patients who definitively required AAE had pelvic ring injury, negative FAST, metabolic acidosis with base deficit worse than −6, and no extra-pelvic sources of bleeding. Prospectively, predictors of arterial injury requiring embolization include age >60, contrast extravasation on CT, patients requiring more than 8 units of PRBC, ISS >16, pelvic hematoma size >500 cm^3, and hemodynamic instability not responsive to resuscitative measures in the absence of other bleeding sources.

It is clear that successful management is best accomplished by a multidisciplinary team approach involving a variety of specialities. The best outcomes can be

expected from a high-volume trauma center that can practice advanced algorithms 24 h per day, 7 days a week, and collect this data for systematic review. Although all trauma centers have interventional radiology available, the considerable variation in the management of this high-risk cohort may be due to differences in institutional systems to provide timely angioembolization and access to orthopedic surgery.

Arterial angioembolization remains a principal choice of treatment for pelvic fractures-related arterial hemorrhage combined with mechanical stabilization of the pelvis. Pelvic angiography can specifically identify the source of bleeding and effectively stop arterial hemorrhage with various embolic agents. However, patients must be carefully selected for embolization. Timely AAE has also been shown to be critical to the outcome and reduction of mortality. Nonselective embolization is considered time-saving, safe, and effective with minimal morbidity [41, 72].

Summary of the Data

- Unfortunately, the management algorithms in recent years have become so complex that they have limited use in practice with no gold standard guidelines or multicenter analysis established (evidence quality moderate; weak recommendation).
- In most clinical situations, operators may attempt more selective embolization. This is often in hemodynamically stable patients or patients who have responded to initial fluid resuscitation (evidence quality moderate; moderate recommendation).
- The best outcomes can be expected from a high-volume trauma center that can practice advanced algorithms 24 h per day, 7 days a week, and collect this data for systematic review (evidence quality moderate; strong recommendation).

Personal View of the Data

The future of trauma care should have diagnostic, operative, and interventional radiological capabilities in one setting. This could be achieved with the addition of a CT angiography system in close proximity to the resuscitation area ameliorating access barriers for timely angiography and embolization.

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Clinical Clearance of the Cervical Spine in the Presence of a Distracting Injury

14

Caleb Van Essen, Edward Hagen, and Brian Williams

Introduction

Early identification and clearance of cervical spine injuries are essential in blunt trauma patients. The potential for devastating consequences from missed injuries must be balanced with the increased morbidity of prolonged and unnecessary cervical spine stabilization [1–4]. Thus, many trauma centers have screening protocols, which often include clinical examination and radiography.

Multiple studies have shown that clinical exam alone is safe to clear the cervical spine without radiography in patients who are awake, alert, lack neurologic deficits, have a negative clinical exam, and particularly lack distracting injuries (DI) [5]. However, many historic and commonly used screening guidelines (NEXUS and Canadian C-spine rules) consider a negative physical examination unreliable in patients with distracting injuries (DI) and require further radiographic imaging to rule out cervical spine injury [5–7]. As a result, liberal use of radiography has been used for screening cervical spine primarily with computed tomography (CT) due to cost, efficiency, and high sensitivity and specificity [8, 9]. Recent literature advocates for more judicious radiographic criteria in patients with DI, citing resource utilization concerns and new data showing improved safety. Patients with DI, create a dilemma for trauma surgeons when clearing the cervical spine. We aim to review the current evidence for recommendations when clearing the cervical spine in blunt trauma patients who are alert, awake, have no neurologic deficits but do have distracting injuries (Table 14.1).

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Table 14.1 PICO clinical question

PICO category	PICO Description
*P*opulation	Blunt trauma patients who are alert, awake, have no neurologic deficits but do have distracting injuries
*I*ntervention	Screening radiographic imaging of cervical spine
*C*omparison	No screening radiographic imaging of cervical spine
*O*utcome	Rate of missed cervical spine injury

Literature Review Process

A literature search of English language publications from 2001 to 2019 was used to identify published data on the clearance of the cervical spine in alert and awake, blunt trauma patients with distracting injuries (DI). Databases searched included: PubMed, Cochrane Evidence-Based Medicine, and guidelines from Eastern Association for the Surgery of Trauma (EAST), Western Trauma Association (WTA), and Advanced Trauma Life Support (ATLS). Terms used in the literature search were "cervical spine," "clearance of cervical spine," "clearing cervical spine," and "distracting injury," "missed cervical spine injuries".

Articles were excluded if they evaluated obtunded/non-examinable patients, if they did not include evaluation of distracting injuries, isolated injury considered to be a distracting injury, i.e., only femur fracture patients. One multi-institutional prospective cohort study, three single institutional prospective cohort studies, and one retrospective study were included in our analysis. The data was classified using the GRADE system. The articles included are listed in Table 14.2.

Summary of Evidence

There are few studies, with no randomized controlled trials, evaluating clearance of the cervical spine in blunt trauma patients with DI. The missed rate of cervical spine injuries in DI patients ranged from 0.2% to 13%. The most robust evaluation of cervical spine injury in presence of DI is by Khan et al., a prospective multi-institutional study, which assessed approximately 3000 examinable blunt trauma patients showing no difference in the rate of clinically missed cervical injuries with or without DI (10.4% vs. 12.6%) [10]. The calculated negative predictive value of clinical exam with and without DI 99% and 98%. The clinical significance of these missed injuries was also questioned as only one patient with a clinically missed injury (0.4%) required operative intervention.

A challenge in many studies is the varying definitions of DI, being very specific (i.e., long bone fractures) or very broad (i.e., clinically apparent pain that might distract the patient from the pain of a cervical spine injury) [11, 12]. Konstantinidis et al. had the most inclusive definition of distracting injury, which included any complaint of non-cervical spine pain. They showed in their evaluation of 88 patients with cervical spine injuries and DI after blunt trauma that only 4.5% had negative

Table 14.2 Literature review evaluating cervical spine injury in alert and awake blunt trauma patients with distracting injuries

First author, year, journal, ref	Study type (level of evidence)	Number of patients	DI patients' rate of missed cervical spine injury (neg clinical exam with + c-spine injury)	Non-DI patients' rate of missed cervical spine injury (neg clinical exam with + c-spine injury)	Sensitivity and NPV of clinical exam with DI NPV	Clinically significant injury: % missed injury patients w/DI requiring treatment intervention (#), type of intervention	Evaluation of C spine	GCS score	Definition of distracting injury
Khan, 2019, J Trauma ACS [10]	Prospective cohort, multi-institutional (moderate)	2929	10.4%	12.6%	90%, 99%	43% (7), 1 patient ORIF, 5 patients cervical collar/ CTO brace	CT (>32 slice)	>14	Skull fracture, >2 facial bone fractures, mandible fracture, intracranial hemorrhage (including subdural hematoma, epidural hematoma, subarachnoid hemorrhage, intraventricular hemorrhage, intraparenchymal hematoma), >2 rib fractures, clavicle fracture, sternal fracture, pelvic fracture, thoracolumbar spine fracture, intraabdominal injury (including solid organ injury, hollow viscus injury, or diaphragmatic injury), femur fracture, tibia/fibula fracture, humerus fracture, radius/ulna fracture, and hip or shoulder dislocation.

(continued)

Table 14.2 (continued)

First author, year, journal, ref	Study type (level of evidence)	Number of patients	DI patients' rate of missed cervical spine injury (neg clinical exam with + c-spine injury)	Non-DI patients' rate of missed cervical spine injury (neg clinical exam with + c-spine injury)	Sensitivity and NPV of clinical exam with DI NPV	Clinically significant injury: % missed injury patients w/DI requiring treatment intervention (#), type of intervention	Evaluation of C spine	GCS score	Definition of distracting injury
Rose, 2012, J Trauma ACS [17]	Prospective cohort single institution (moderate)	761	0.2%	1.7%	99%, 99%	100% (1), cervical collar	CT	>14	Categories: head, torso, long bone injury
Heffernan, 2005, J Trauma [14]	Prospective cohort, single institution (moderate)	406	2.9% (5% upper torso injury vs 0% lower torso injury)	NA	NA	Not defined	Not defined	Not defined, excluded if unable to comply with questions	AIS >2, Lower torso injuries: abdomen, pelvis, lower extremities or lumbar spine. Upper torso injuries: head, neck, face, upper extremity, chest, diaphragm, or thoracic spine
Drew, 2015, Mil Med [15]	Retrospective, dept. of defense trauma registry (low)	149	13%	NA	NA	Not defined	CT, +/− MR	>14	Categories: head, torso, or long bone/extremity injuries. Open wounds >5 cm, fractures, and other painful injuries
Konstantinidis, 2011, J Trauma [13]	Prospective cohort, single institution (low)	101	4.5%	NA	NA	50% (2), cervical collar	Not defined	>13	Any immediately evident bony or soft tissue injury or a complaint of non–c-spine pain whether or not an actual injury was subsequently diagnosed

clinical examination. As all these "potential missed injuries" were isolated to the upper torso, they concluded that a more narrowed definition was required for DI, limiting it to upper torso injuries/pain [13]. Similarly, Heffernan et al. aimed to delineate DI that had the greatest effect on clinical examination showing upper torso injuries having an associated miss rate of 5% with no effect from lower torso injuries [14]. Drew et al. retrospective study from military trauma had a 13% miss rate in the setting of DI; however, they also showed that 85% of these patients had DI that were in close proximity to the neck in the upper torso as compared to the lower torso 15%. Of note, they only examined patients with midline tenderness, without assessing the movement of the neck [15]. Dahlquist et al. showed similar sensitivity and negative predictive value to the original NEXUS study when they redefined the definition of distracting injury to exclude femur fractures. Of patients that only met NEXUS imaging criteria for femur fracture, only 2 (0.6%) patients had cervical spine injuries, for a sensitivity of 96% [16].

Rose et al. completed a 2-year prospective study on blunt trauma patients with broad inclusion criteria for distracting injuries. Their group only found 1 patient (0.2%) with a missed injury, who was subsequently treated with a cervical collar. In addition, 53% of these patients had more than one DI. They also address how clinical exam alone can have a significant financial benefit ($156,000/year decrease in total patient charges) and reduction in radiation exposure while maintaining a low miss rate [17].

Guidelines

The EAST guidelines, updated to 2009, give a level 2 recommendation requiring CT imaging to evaluate cervical spine injury in awake, alert patients without neurologic deficit who have no neck pain or tenderness with a full range of motion of the neck who also have distracting injuries. Distracting injuries were not defined in their recommendations [18].

The WEST guidelines, as seen in their most recent prospective multi-institutional study on spine clearance in 2016, require CT imaging if patients fail to meet NEXUS or Canadian C-spine criteria [19].

The ATLS guidelines from the tenth edition are consistent with NEXUS and Canadian C-spine rules with NEXUS criteria requiring imaging for patients with distracting injuries and Canadian C-spine rules do not specifically include DI in their screening algorithm but use mechanism of injury [20].

Recommendations

- Blunt trauma patients who are alert, awake, without neurologic deficits but do have distracting injuries require additional imaging to clear the cervical spine (Grade 1B, evidence quality moderate, recommendation strong).

- Omitting additional imaging to clear the cervical spine may be considered in patients with isolated lower torso distracting injuries (Grade 2B, evidence quality moderate, recommendation weak).
- Future studies are needed to more clearly define distracting injuries (Grade 1B, evidence quality moderate, recommendation strong).

Personal Perspective

The current level of evidence is not sufficient to change current recommendations on clearing the cervical spine in patients with distracting injuries, as the rate of missed cervical spine injuries ranged up to 13%. Thus, the financial burden and radiation exposure of a highly sensitive and specific cervical spine imaging (CT or MR) needs to be balanced with the morbidity of missed cervical spine injury. However, more evidence in recent years suggests that the probability of a clinically significant spinal column injury in this patient population is low, and that cervical spine collars can probably be safely removed.

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MRI Clearance for the Cervical Spine

15

Marc de Moya and Amy Elizabeth Murphy

Introduction

Trauma is the leading cause of death and disability in the United States, and the majority of this trauma is via blunt mechanism. The American College of Surgeons Committee on Trauma recommends that all patients with multiple blunt injuries should restrict the movement of the cervical spine (c-spine) until assessed further with imaging and physical exam [1]. The incidence of patients with blunt trauma-associated c-spine injury is 1–4% [2, 3]. Patients who are awake and alert and able to be evaluated, who also do not have significant distracting injuries, can be clinically cleared using the National Emergency X-Radiography Utilization Study rule [4–6].

Clearing the c-spine of injury after blunt trauma in patients who are obtunded is often difficult and an area of debate in the trauma field [2, 3]. Obtunded refers to those who have an unreliable clinical exam due to decreased Glasgow Coma Score (GCS) [3]. Clearing the c-spine with inadequate criteria can lead to missing a significant and possibly intervenable c-spine injury and subsequent permanent neurologic injury [2]. In an unconscious patient, the incidence of c-spine injury is as high as 34% [3, 7]. On the other hand delayed clearance of the c-spine is also associated with significant complications, for example, aspiration, increased intracranial and airway pressures, delayed weaning from the ventilator, and development of decubitus ulcers [3, 8, 9].

Establishing facility guidelines on how to clear a c-spine is important when managing these patients [2]. Flexion and extension X-rays have fallen out of favor as initial protocols for c-spine clearance in obtunded patients. Computed tomography scans (CT scans) from occiput to T1 with sagittal and coronal reconstruction are

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currently the gold standard as the initial radiographic evaluation of the c-spine due to the high sensitivity and specificity [2, 3]. There has been some debate, however, about the possibility of missing ligamentous injuries on the CT scan. Magnetic resonance imaging (MRI) is now used as a diagnostic tool to clear the c-spine in those cases where the CT scan was equivocal or could not be correlated with a clinical exam. In this chapter, we will discuss the literature regarding CT scan versus MRI clearance of the c-spine.

Search Strategy

Our search strategy was the following on PUBMED: (((((("2010"[Date - Publication] : "3000"[Date - Publication])) AND randomized controlled trial[Publication Type]) OR controlled clinical trial[Publication Type]) OR meta analysis[Publication Type]) AND cervical spinal clearance) AND trauma. Thirteen articles were found. Seven papers were meta-analyses of the most recent data. There was a single-center prospective analysis. The remaining were older or lower evidence papers.

We also searched the Western Trauma Association (WTA) and the Eastern Association for the Surgery of Trauma (EAST) for consensus documents on c-spine clearance. There was a WTA multi-institutional trial published in 2016 regarding c-spinal clearance. The EAST organization also has a systematic review and practice management guideline from 2015. The PICO table guiding the literature review of this chapter is in Table 15.1.

Results

Cervical collars are placed on all patients who meet the criteria for c-spine clearance. In the obtunded patient, whether that is from traumatic brain injury, alcohol, recreational drugs, or unclear causes, one is unable to assess the degree of pain or neurologic symptoms that the patient is experiencing related to the c-spine. These patients would require a radiologic clearance of the c-spine.

Guidelines recommend that patients who have a significant traumatic mechanism, altered GCS, intoxication, neck pain, neurologic deficit, or distracting injury should undergo screening CT scan of the c-spine to rule out injury [4–6, 10]. The sensitivity of a multidetector CT scan of the c-spine was found in one meta-analysis by Raza, et al. to be 100% [3]. Inaba et al. performed a WTA multi-institutional trial, published in 2016, to evaluate the sensitivity and specificity of the CT scan to detect a clinically significant c-spine injury [2]. This study found that CT scan had

Table 15.1 PICO Table

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Obtunded patients after blunt trauma	High-resolution CT scan AND MRI	High-resolution CT scan without MRI	Morbidity of missed cervical spine injuries

a high sensitivity (98.5%) and specificity (91.0%) to identify significant fractures after blunt trauma [2]. Ultimately, EAST guidelines recommended that cervical collars may be removed after high-quality CT scan if the image is adequate and negative for acute injuries [10, 11]. Western Trauma Association also deemed CT scan imaging an appropriate screening modality alone for obtunded patients with blunt trauma [2, 12].

MRI Screening

One single-center prospective evaluation done by Stelfox et al. demonstrated that patients who underwent a CT scan of the c-spine, only, to determine spinal clearance had fewer days of immobilization (6 days vs. 2 days). Despite the high sensitivity and specificity of CT scans, an increasing number of reports advocate for a more liberal use of MRI to detect an unstable injury not seen on the CT scan. Some studies have looked at adding MRI of the c-spine in an effort to detect soft tissue injuries not seen on screening CT scans [3]. MRI has the potential to rule out occult spinal cord injuries and has become the diagnostic tool of choice to identify ligamentous, spinal cord, or disc injuries in patients after blunt trauma [13]. In a meta-analysis by Muchow et al., the authors quantified the ability of MRI to clear a c-spine in an obtunded patient by evaluating 5 level 1 protocols [13]. A normal c-spine MRI had a negative predictive value of 100% leading the authors to conclude that when an MRI discloses nothing abnormal, a significant injury does not exist. The positive predictive value of an MRI that had an abnormality was 90.2% [13]. Sensitivity in this study was found to be 97.2% and the specificity was 98.5%. The recommendation is that if an MRI is negative for acute findings, the c-spine should be deemed cleared of ligamentous or soft tissue injury. With regard to potentially missed injuries, Malhotra et al. found in their meta-analysis a 15% rate of abnormalities on MRI in patients with normal CT scans of their c-spines in 23 studies [8]. Ligamentous injuries were the most likely to be reported, which most often required 4–12 weeks more of cervical immobilization. The study did note a lack of follow-up reporting in the literature for these types of patients to evaluate if ligamentous changes evolve or improve over time with immobilization [8]. The authors reported only 16 of the 5286 patients included in the meta-analysis (0.30%), had an unstable injury visualized on MRI requiring surgical stabilization in the face of a normal CT scan [8]. In the WTA trial, 1.5% of patients with a negative CT scan of the c-spine had MRI reading that warranted hard collar prescription, most often a strain or sprain.

MRI was only used as a diagnostic tool when patients had clear neurologic deficits [2]. Another study by Russin et al. demonstrated that 10% of the 855 patients undergoing MRI were found to have positive findings in the setting of negative CT scan [14]. Fifty-two percent had changes in their management including prolonged cervical spinal immobilization and/or further imaging. Only 1% of patients with negative CT scan and a positive MRI, however, had instability requiring surgical stabilization. In a meta-analysis by Schoenfeld et al., 12% of patients had

abnormalities detected on MRI after a normal CT scan. Forty-four percent of these injuries were found to be ligamentous injuries, 25% were degenerative changes and only 2% were fractures or dislocations. In total, 6% of the patients had a change in management based on MRI where only 1% of the cohort required surgical stabilization [7]. Lastly, after 1700 patients had negative CT scans, 15.8% had abnormalities found on MRI in a meta-analysis done by Plackett et al. The most common finding was contusion, ligamentous injury, or spinal cord edema [15]. Only 0.3% underwent surgical intervention after MRI was obtained [15]. Ultimately, based on moderate quality evidence, the rate of occult c-spinal injury diagnosed by MRI in the setting of a normal high-quality CT scan only 0.3–1.5% required surgical intervention [7, 14–16].

Timing and Risk of MRI Clearance of C-Spine

In the meta-analysis by Muchow et al., MRI was most often performed between 24 and 72 h [13]. They mention that no study has been performed to clarify the optimal time for MRI. They finally recommend that MRI is performed within 48–72 h of injury as the best time to detect soft tissue injury and minimize false-positive results. Some institutions argue that MRI is not necessary for the face of a negative high-quality CT scan. MRI has been found to be costly and risky. The risk of transporting a patient to an MRI who is obtunded needs to be considered and is not insignificant [2, 8]. Studies have demonstrated between 17.8 and 51% risk of complications when transporting patients to the MRI [17]. Lastly, in some studies, MRI has been shown to have an associated false-positive rate of 6–40%, which could lead to many unnecessarily immobilized patients with hard collars, as well as increased emotional, psychological, and patient distress [7, 13].

Recommendations Based on the Data

The best interpretation of the data is that if a patient fails to qualify for clinical clearance, they should undergo c-spine CT scan imaging from the base of the skull to T1. Table 15.2 summarizes the data reviewed in this chapter. High-quality cervical CT scan has low false-negative rates, high negative predictive value, high sensitivity, and specificity. The cervical CT scan is rapid and safe for most patients. If the CT scan is negative, but the patient has a neurologic deficit, then MRI should be done for diagnostic purposes.

Summary of Recommendations

- Patients who are obtunded with an altered mental status and disability should undergo screening CT scan of the cervical spine to rule out spinal cord injury (evidence quality moderate, strong recommendation).

Table 15.2 Outcomes

Study author	*n*	Outcome of data	Level of evidence
Inaba, Kenji, et al.	10,276	– CT rules out significant cervical spinal injury (SN 98.5%). – If patients have an abnormal neurologic exam, there is a small chance of missing an injury, so MRI is warranted	Level 2
Raza, Mushahid, et al.	53	– The sensitivity of a multidetector CT cervical spine is 100%. – Cervical spine can be cleared in the setting of obtunded patients if there is a normal CT scan	Level 3
Muchow, Ryan D., et al.	464	– MRI demonstrated a 100% negative predictive value in clinically unevaluatable patients. – MRI gives a false-positive rate of 25–40%	Level 3
Malhotra, Ajay, et al.	286	– There is a 15% incidence of finding an abnormality on an MRI in the setting of a normal CT cervical spine. – The overall risk of finding an unstable injury requiring surgery is between 0.0029 and 0.3%	Level 3
Patel, Mayur B., et al.	1017	– There is a 9% possible incidence of stable injury found on MRI when high-quality CT scan is performed. – Recommend that in an obtunded patient with blunt trauma, cervical collars should be removed after a negative high-quality CT scan	Level 3
Stelfox, Henry Thomas, et al	215	– CT scan clearance was associated with significantly lower morbidity than MRI clearance	Level 4
Russin, Jonathan J., et al.	1322	– 13% of patients with negative CT cervical spine had positive findings on MRI. – 0.3% of the entire group who had negative CT results required surgical stabilization. Negative predictive value of a negative CT scan of the cervical spine is 99.6%	Level 3
Schoenfeld, Andrew J., et al.	1550	– 12% of patients with a negative cervical CT scan had abnormalities on MRI – 1% required surgical stabilization – False-positive rate of MRI of the cervical spine was 6%	Level 3
Halpern, Casey H., et al.	464	– CT scan and MRI are very expensive compared with cervical collar immobilization – Specificity of CT scan is 99.9% and MRI is 99.7% – Sensitivity of CT scan is 83.2% and MRI is 86.7%	Level 3
Plackett, Timothy P., et al.	1214	– 15.8% of patients who had a negative CT scan had an abnormality on MRI. –0.3% of abnormalities found on MRI required surgical intervention	Level 3

- Patients who have a negative CT scan have a 0.3–1.5% chance of having an occult cervical spinal injury diagnosed on MRI requiring surgical intervention. Due to this low risk, routine MRI is not recommended (evidence quality moderate, moderate recommendation).
- Patients who have neurologic deficits should undergo further diagnostic MRI of the cervical spine (evidence quality moderate, moderate recommendation).

Personal View of the Data

In our institution, if the patient meets high-risk criteria for c-spine injuries they will undergo a CT scan of the c-spine (Fig. 15.1). If the CT scan is adequate and negative and the provider is able to clinically clear the patient, we removed the cervical immobilizer. If the CT scan is normal, but the patient is obtunded and/or unable to cooperate with a physical exam, we will wait 24–48 h to re-evaluate for any neurologic deficits off sedation. If the patient has an intact gross motor exam, we will remove the collar and document. If the patient still has no ability to give a motor exam, we will then re-evaluate in another 24 h. If we cannot determine if there are motor deficits or if the gross motor exam is not intact, we will obtain an MRI of the c-spine by 72 h.

If the CT scan of the c-spine is abnormal with chronic findings that include ankylosing spondylysis, diffuse idiopathic skeletal hyperostosis, or cervical stenosis but the patient is examinable, the collar is removed. If the exam is unable to be obtained or is abnormal we obtain an MRI.

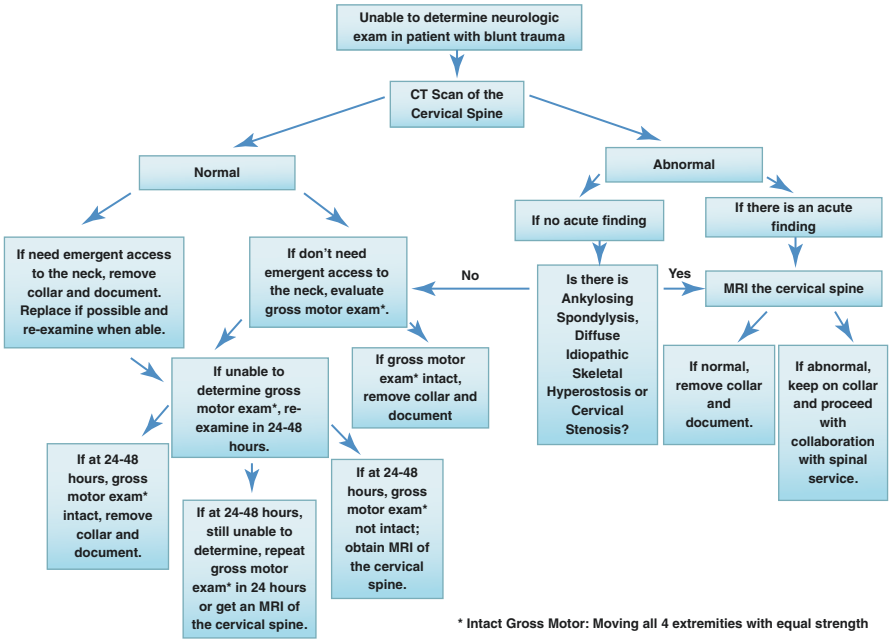

Fig. 15.1 MRI C spine pathway

If either the CT scan of the c-spine or the MRI of the c-spine are abnormal with acute findings, then we consult our spine service for further recommendations for management. We believe this is the safest way to protect our patients and avoid neurologic disasters.

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Part V

Traumatic Brain Injury

ECMO Safety in the Setting of Traumatic Brain Injury

16

Brandon Masi Parker, Jay Menaker, and Deborah M. Stein

Introduction

Trauma is a leading cause of death worldwide. Trauma mortality is significantly increased by the presence of traumatic brain injury (TBI) and acute respiratory distress syndrome (ARDS) [1, 2]. ARDS occurs in 20–30% of trauma patients with brain injury [3]. The treatment of patients with TBI and ARDS is complicated by conflicting interests in the management of the two severe disease processes. Permissive hypercarbia, elevated positive end-expiratory pressures (PEEP), use of steroids, and prone positioning have shown effective in the management of ARDS [4–6] but can be detrimental to the brain-injured patient. Despite historical views, venovenous extracorporeal membrane oxygenation (VV ECMO) has become a viable option for TBI patients with ARDS. The goal of VV ECMO in TBI is to support the patient through inadequate oxygenation and ventilation and prevent secondary injury to injured brain.

The use of VV ECMO is a difficult decision that often requires a complex risk-benefit calculation. The use of ECMO itself carries significant morbidity that must be weighed against the morbidity of the diseases of ARDS and TBI. The pertinent complications of ECMO include bleeding in up to 20% of patients [7], infectious

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Table 16.1 PICO table

P (Population)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with traumatic brain injury and ARDS	Venovenous ECMO	Standard of care	Mortality, neurologic function, bleeding complications

complications in up to 65% of patients [8], neurologic injury in the absence of TBI in around 13% of patients, and an unknown amount of post-traumatic stress disorder [9].

A randomized controlled trial comparing management of ARDS in the setting of TBI with conventional versus ECMO management has not been done. The decision to utilize ECMO in the management of these patients is thus based on available retrospective data and extrapolation from literature pertaining to non-trauma-related ARDS. We explored the available data with the query focused on the PICO question shown in Table 16.1.

Search Strategy

Our search strategy was to use the terms (((((“traumatic brain injury”) AND “extracorporeal membrane oxygenation”) AND (“2010”[Date - Publication]: “3000”[Date - Publication]))))) AND English[Language].

Results (Table 16.2) were limited to case reports, case series, and review articles due to the nature of the intervention being investigated. Therefore, this search and other reviews of the literature do not provide high-quality data to base decisions on.

Recommendations Based on the Data

After the analysis of the literature and experience with my patients, we have found that VV ECMO is a safe and effective tool in select TBI patients.

VV ECMO can be safely performed with low-dose or no systemic heparin in the era of heparin bonded circuits (evidence low quality; weak recommendation).

Patients in the immediate resuscitation period without head imaging should be placed on ECMO if they cannot be adequately oxygenated or ventilated and there is an absence of lateralizing neurologic deficit or sequela of chronic disease (evidence very low quality; weak recommendation).

Patients with TBI and ARDS that have failed traditional ventilator management should be placed on ECMO to avoid hypercarbia and hypoxia (evidence low quality; weak recommendation).

Systemic anticoagulation can be safely held during the initiation of ECMO if the stability of TBI has not been established by serial brain imaging (evidence low quality; weak recommendation).

Table 16.2 Summary of data related to use of ECMO in patients with TBI

Study	Type of study	Summary/ conclusions	Complications	Outcomes	Quality of evidence
[10]	Review	Prevention of hypoxia and hypercarbia is paramount in TBI and difficult with ARDS. ECMO is a potential rescue therapy	The authors expressed concern for anticoagulating these patients	N/A	Very low quality
[11]	Case report	Multi-trauma patient with TBI and hypoxic respiratory failure placed on VV ECMO with systemic heparinization	None reported	Tolerated bolus heparin for cannulation and systemic heparin infusion after 48 h. Discharged home after inpatient rehab stay	Very low quality
[12]	Case series	Three patients with multiple injuries including TBI were placed on VV ECMO for ARDS. ECMO was performed without systemic anticoagulation for 3–5 days	Thrombus noted in inferior vena cava that resolved on follow-up	All patients discharged home through inpatient rehabilitation	Very low quality
[13]	Case series	Seven patients with multiple injuries including TBI with hypoxic respiratory failure placed on VV ECMO without systemic heparin and maintenance of high flow (4–5 L/ min)	Pressure sores and bleeding from cannula site reported	All survived to discharge with improved neurologic status. No worsening of TBI on cat scan (CT) follow-up	Low quality
[14]	Clinical review	A general review of recent large studies of ECMO patients that included patients with intracranial hemorrhage	N/A	Patients at high risk for bleeding with recent intracranial hemorrhage can be supported with reduced or held anticoagulation	Very low quality

(continued)

Table 16.2 (continued)

Study	Type of study	Summary/ conclusions	Complications	Outcomes	Quality of evidence
[15]	Case report	21-year-old male blunt trauma with TBI. Supported on ECMO for 20 days. First 5 days without systemic anticoagulation	3 thrombosed oxygenators in first 5 days off of anticoagulation	Home without neurologic deficit	Very low quality
[16]	Case series	Pumpless extracorporeal lung assist (pECLA) for decarboxylation in 10 patients with TBI and ICP monitoring and placed on systemic anticoagulation	None reported	pECLA found to be safe and effective in managing CO_2 and assisting in ICP management	Very low quality
[17]	Case series	Two patients with concomitant TBI and ARDS on ECMO with systemic anticoagulation	None reported	Both patients with complete neurologic recovery	Very low quality
[18]	Retrospective cohort study	Review of patients with trauma and ARDS compared against historical controls. ECMO patients with systemic AC at "low goals" and driven by thromboelastogram	Of the 2 patients with TBI, 1 patient had a UE thrombosis and extracranial bleeding	Improved mortality for trauma patients on ECMO compared to historical controls. Subgroup of brain-injured patients	Low quality
[19]	Review	This review written by neuro-intensivist on management of ARDS in the setting of brain injury	N/A	ECMO is effective and safe in "select patients" with TBI and ARDS and further studies needed to decide on AC goals	Very low quality

Table 16.2 (continued)

Study	Type of study	Summary/ conclusions	Complications	Outcomes	Quality of evidence
[20]	Systematic review	12 studies reviewed with a total of 215 trauma patients placed on ECMO. 23 of these patients had traumatic brain injury	None reported related to traumatic brain injury	Subset analysis of TBI patients showed survival range from 60 to 93% with no mortalities related to TBI and trend toward decreased anticoagulation goals	Low quality
[21]	Retrospective chart review	Single center before and after comparison following a policy change to heparin-sparing protocol for VV ECMO revealed no change in bleeding, thrombosis, or survival	No statistical difference for bleeding (32% and 33%) or for thromboembolic events (18% and 39%) for heparin-sparing compared to full heparin	No significant difference in survival, bleeding, thromboembolic events or transfusion requirements noted after changing to heparin-sparing strategy	Low quality
[22]	Retrospective cohort study	Propensity score-matched evaluation of 744 patients from ELSO registry showed higher rates of intracranial hemorrhage (ICH) with larger cannulas	4.3% of patients experience ICH with 31 Fr when compared to 1.6% with 27 Fr (P0.03)	Recommendation for smaller cannulas when possible	Moderate quality

Systemic anticoagulation can be initiated once serial brain imaging has shown stable TBI and serial brain imaging should be continued once anticoagulation has been initiated to monitor for changes in intracranial hemorrhage (evidence low quality; weak recommendation).

Smaller cannula placed in femoral–femoral configuration should be used when possible to reduce the risk of worsening intracranial hemorrhage (evidence moderate quality; weak recommendation).

Summary of Recommendations

- VV ECMO can be safely performed with low-dose or no systemic heparin in the era of heparin bonded circuits (evidence low quality; weak recommendation).
- Patients with TBI and ARDS that have failed traditional ventilator management should be placed on ECMO to avoid hypercarbia and hypoxia (evidence low quality; weak recommendation).
- Systemic anticoagulation can be safely held during the initiation of ECMO if stability of TBI has not been established by serial brain imaging (evidence low quality; weak recommendation).
- Smaller cannula placed in femoral–femoral configuration should be used when possible to reduce risk of worsening intracranial hemorrhage (evidence moderate quality; weak recommendation).

A Personal View of the Data

In our personal practice, TBI is not a contraindication to VV ECMO. The difficult decision of whether or not to support a patient with VV ECMO after TBI is influenced by a patient-specific consideration of the risks and benefits of VV ECMO. Thus, the decision should be based primarily on whether the patient has failed traditional maximal conventional therapy with the caveat of certain ventilatory strategy restrictions imposed by the presence of TBI. After the decision is made to proceed with ECMO the subsequent difficult decisions are primarily focused around the level of anticoagulation and cannulation strategy.

The plan for anticoagulation is made with continuous input from neurosurgical colleagues. The primary interest is observing the stability of intracranial hemorrhage, defined as consecutive axial brain imaging without expansion or worsening of hemorrhage. With the use of heparin-bonded circuits, it is our practice to avoid systemic anticoagulation in the setting of acute TBI and once stability of brain injury is established, we initiate systemic anticoagulation with a partial thromboplastin time (PTT) goal of 45–55. We routinely hold heparin boluses in the acute setting of TBI and will consider a reduced heparin bolus if TBI stability has already been established.

Our preferred cannulation strategy in this population is femoral–femoral VV ECMO. In this configuration, the patient does not need a large (>27Fr) cannula placed in the internal jugular veins. The reason for avoidance of large cannula in the internal jugular veins is the theoretical risk of decreased venous return and the observational evidence of increased risk of intracranial hemorrhage with larger cannula.

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Can Abdominal Decompression Improve Refractory Intracranial Hypertension?

17

Mira Ghneim and Thomas M. Scalea

Introduction

Traumatic brain injury (TBI) is a leading cause of death and lifelong disability among adults in the United States (U.S). In 2010, the Centers for Disease Control and Prevention estimated that TBI accounted for approximately 2.5 million emergency department visits, hospitalizations, and deaths in the U.S, either as an isolated injury or in combination with other injuries [1]. While the clinical spectrum of TBI is broad, current management strategies of severe TBI utilize both medical and surgical therapies (decompressive craniotomy/craniectomy) to minimize secondary brain injury [2]. Over the past decade, outcomes for patients with severe TBI have improved, and this improvement in outcomes can be attributed to a better understanding of the pathophysiology of TBI, improved critical care strategies, and increased awareness of extra-cranial factors such as multicompartment syndrome (MCS) that may affect outcomes after TBI.

In the torso, elevations in intra-abdominal pressure (IAP) increases intrathoracic pressure which may lead to a rise in intracranial pressure (ICP). MCS occurs due to the sequential elevation in several compartments that cause physiologic derangements [3]. In patients with severe TBI, MCS can further increase ICP leading to the development of intracranial hypertension (ICH) which is known to be associated with poor neurologic outcomes [4–8]. While the incidence of MCS is low, 2% during a 4-year period at our institution, mortality for MCS patients was significant [5]. This chapter will review the evidence available describing the influence of IAP on ICP in severe TBI, and whether the treatment of patients with severe TBI, and refractory ICH, can be optimized by surgical management of increased IAP through a decompressive laparotomy (DCL) (Table 17.1).

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Table 17.1 Population, intervention, comparator, and outcomes (PICO)—abdominal decompression vs. standard medical therapy to treat refractory intracranial hypertension

Population	Severe TBI patients with refractory ICH
Intervention	Decompressive laparotomy
Comparator	Maximum standard of care management of TBI (elevated head of bed, sedation, analgesia, normotension, normocarbia, normothermia, mannitol, 3% saline, cerebrospinal fluid drainage, barbiturates, ± neurosurgical intervention) without decompressive laparotomy
Outcome	Reduction of refractory ICH and improved outcomes

Search Strategy

This was a PubMed (https://www.ncbi.nlm.nih.gov/pubmed), MEDLINE/OVID, and Internet search using the Google Scholar (http://scholar.google.com) on the topic of intra-abdominal pressure, intra-abdominal hypertension, abdominal compartment syndrome, multiple compartment syndrome, and decompressive laparotomy for refractory intracranial hypertension. Publications from January 1994 to December 2016 were reviewed. The literature reviewed included case/brief reports, a prospective trial, clinical notes, expert panel reports, review articles, guidelines and multiple original articles and references within the selected articles were also reviewed.

Results

Management of Elevated Intracranial Pressure and Intracranial Hypertension

ICH is defined as an ICP of >20 mmHg [7] and is associated with increased morbidity and mortality [4]. ICP monitoring is often used in severe TBI focusing on treatment of elevations of ICP and ICH [7]. Medical management for ICP includes a step wide use of sedation, analgesia, targeted temperature management to maintain normothermia, hyperosmolar therapy with mannitol or hypertonic saline, and barbiturate coma in rare cases [2]. Decompressive craniectomy (DC) in the absence of an evacuatable mass lesion which allows the brain parenchyma to expand beyond the confines of the cranial vault is the primary surgical strategy utilized in the management of ICH. A recent randomized controlled trial by Chestnut et al. has challenged the need for ICP monitoring, failing to show any benefit in functional recovery and mortality [8]. DC has been shown to be associated with improved cerebral blood flow and oxygenation, but like ICP monitoring, in recent years, the efficacy of decompressive craniectomy has been challenged [9–12]. Timmons et al. showed no functional benefit to decompressive bifrontal craniectomy in the setting of refractory ICH [13]. In 2016 the RESCUEicp Trial showed similar results [14]. While mortality at 6 months was improved in the craniectomy group, those who survived had worse disabilities.

Pathophysiology of Elevated Intra-Abdominal Pressure

IAP is defined as the steady-state pressure within the abdominal cavity. Under physiological conditions, values of 5–7 mmHg are considered normal in critically ill adults. Intra-abdominal hypertension (IAH) is defined as a sustained or repeated pathologic elevation of IAP ≥12 mmHg and is graded from 1 to 5 (IAP range 12 to >25). Abdominal Compartment Syndrome (ACS) is defined as sustained IAP >20 mmHg with new organ dysfunction/failure [15]. There are many non-operative options (sedation, paralytics, paracentesis, diuretics and dialysis) for the management of increased IAP. However, once ACS develops DCL is recommended [15].

Two main mechanisms control the interaction between the abdominal cavity and the central nervous system. The first mechanism is dependent on the valveless vertebral venous system (VVS) that allows bidirectional flow such that pressure change in the abdominal cavity shifts venous blood flow to the spinal canal and the calvarium [16]. Secondly, an increased IAP has an influence on the intrathoracic pressure. Cerebrospinal fluid (CSF) and the brain's venous drainage occurs through the jugular veins and the VVS. Elevations in the IAP are transferred into the thoracic compartment leading to elevation of the diaphragm and increased intrathoracic pressure, with subsequent rise in central venous pressure therefore impeding the drainage of CSF and blood through the jugular veins [3, 17]. Based on the Monro–Kellie doctrine, the cranium is a rigid vault filled to capacity with non-compressible brain tissue, CSF, and blood. If one of the three components increases in size, the volume of the other two has to decrease, in order to maintain equilibrium and to prevent a rise in ICP [18]. Therefore, an increase in IAP will result in a subsequent increase of the intracranial volume of venous blood and can cause increased ICP and the development of ICH.

Management of patients with severe TBI is complex, particularly in polytrauma patients with other injuries that often bleed. Aggressive resuscitation is often needed to support oxygen delivery and to augment cerebral perfusion pressure particularly in the setting of hypotension [19]. This same resuscitation may then increase IAP, intrathoracic pressure and thus increase ICP.

The relationship between IAP and ICP has been recognized for some time. In the early 1990s, Joseph et al. first reported increases in ICP in swine with pre-existing ICH with balloon insufflation for laparoscopy [20]. Additional animal studies confirmed that increased IAP was associated with increased intra thoracic pressure (ITP) and subsequent increase in ICP [21, 22]. One animal model looking at the effect of CPR on ICP confirmed the interplay between IAP, ITP, and ICP. While ICP increased during CPR, placement of an abdominal binder further worsened the increase in ICP [23]. In the early 2000s, a prospective study by Citerio et al. [31] demonstrated that increases in IAP during laparoscopy caused significant increases in ICP in patients with TBI and recommended caution in utilizing laparoscopy in TBI patients, and routine assessment of IAP to help clinicians identify remediable causes of increased ICP. The relationship between ITP, IAP, and ICP is well established in both animal and human series [24–28].

Our Novel Approach

Our institution was the first to report utilizing DCL to treat refractory ICH in two trauma patients with refractory ICH after traditional methods of lowering ICP were maximized in the setting of mildly elevated IAP [29–30]. Both patients had improvement in hemodynamics, pulmonary function, as well as decreased ICP and improved GCS. Both patients were eventually discharged to rehabilitation facilities.

Following the success with the two cases described above, the Shock Trauma team began to routinely measure IAP in patients with refractory ICH. Between 2000 and 2003, 17 patients underwent DCL for refractory ICH. Thirteen were male and four were female. The mean age was 29.1 years with a range of 17–64 years. All patients sustained blunt force trauma with mean ISS 29.5 (range 17–41), mean GCS 9 (range 4–14), and mean head AIS 4.5 (range 3–5). All patients underwent ICP monitoring within 6 hours of presentation. All patients were managed per standard of care. Large intravenous volumes were used to maintain cardiac output and cerebral perfusion pressure (CPP).

Patients were in a markedly positive fluid balance (+28 liters) at the time of decompression. All of the patients underwent DCL solely to treat their refractory ICH done at a mean of 5.8 days after admission (range 4–13 days). At the time of decompression none of the patients had clear signs of ACS with mean IAP 27.5 ± −5.2 (range 21–35 mmHg). Increased airway pressures were not evident, as patients had a mean airway pressure of 29.5 mmHg. Renal function was similarly maintained, with a mean urine output of 2.7 liters over 12 hours.

ICP dropped immediately post decompression, and in some, continued to drop within the following 6–12 hours without further therapy. Overall survival rate was 65%. All survivors were eventually discharged to a rehabilitation facility. Non-survivors were more likely to have been treated with barbiturate coma or undergo a DC when compared to the survivors. Given the results, it was concluded that refractory ICH maybe one of the earliest signs of ACS, and elevations in ICP that are refractory to medical therapy with concurrent IAH should be treated with a DCL, even without clear evidence of ACS [31].

Multicompartment Syndrome

In 2007, the concept of MCS was first defined [30]. Characteristics and outcomes of 102 patients who sustained blunt injury with subsequent severe TBI at The R Adams Cowley Shock Trauma Center were reviewed. Patients who underwent DC alone to decrease ICP were thought to have isolated ICH. Those who had DC in combination with DL were thought to have MCS. The incidence of MCS was 2% over a 4-year period. Mean age was 29.5 years, mean ISS 34.4, and admission GCS of 7.1. 76% underwent DC alone, and 22% of patients had a DC and DCL for MCS. Fourteen

percent underwent DC before DCL and 8.8% underwent DCL before DC. MCS patients were more critically ill on admission, with higher ISS and mean ICP at time of decompression compared to those who underwent DC alone. Larger volume fluid resuscitation for CPP maintenance, correction of sedation induced hypotension and hypertonic saline may have led to the development of MCS given that those who developed MCS received 23 liters more than those who did not in the first 7 days of hospitalization.

Those who underwent DC first had higher ICPs than those who underwent DCL first. IAP was elevated at the time of DCL with the mean IAP of 28 ± 5 mmHg. There were statistically significant decreases in ICP after DCL and DC, regardless of whether the DL was done before or after DC. In addition, DCL was successful in reducing ITP. Outcomes in patients developing MCS were worse than those with elevated ICP alone with a 12% absolute increase in mortality for DC alone vs. DC plus DCL, although not statistically significant. In patients with both IAP elevation and refractory ICH, the order of DC and DCL did not have a significant effect on mortality. The only significant predictor for survival in MCS was younger age. Higher GCS, lower volume of resuscitation, shorter time to DCL, avoidance of DC, and avoidance of barbiturate coma were all associated with survival in MCS but did not reach statistical significance. The results once again confirmed the influence of IAP and ITP on ICP. While refractory ICH can be attributed to the head injury alone, in the setting of polytrauma, MCS should be suspected for refractory ICH that is not responsive to maximal medical and surgical therapy.

Recommendations Based on the Data

The relationship between IAP, ITP, and ICP seems irrefutable. Limiting ICP with sedation, targeted temperature management, hyperosmolar therapy to reduce brain water and mild hyperventilation suffices in most cases. In cases of severe TBI refractory to standard therapy, standard therapy is effectively always insufficent. In such patients with severe injury, large volume resuscitation is required. Severe shock can produce capillary leak syndrome and maintaining adequate intravascular volume requires large volumes of fluid for resuscitation. This increase in IAP and leads to the development of ACS. Symptoms of early ACS can be insidious. Hypotension, oliguria, and acidosis may represent early ACS or may simply be the consequences of the severe injury. As IAP continues to increase, the hypoxia and the need for increased ventilatory pressures from secondary increases in ITP may simply be interpreted as direct pulmonary injury or early ARDS. Finally, the subsequent increases in ICP may be incorrectly ascribed to primary brain injury. Thus, clear recognition of the cascade that can lead to MCS is paramount to avoid missing serious recalcitrant ICP. Early MCS management should be strongly considered for intractable ICP to maintain neurologic function.

Summary of Recommendation

- Decompressive laparotomy is recommended in multiply injured patients who present with symptoms of MCS and refractory ICH in the setting of maximum medical therapy (evidence quality moderate; weak recommendation).

A personal View of the Data

Early in our experience, we began to recognize that abdominal pressures that were relatively normal (in the range of 25 mm Hg) could impact ICP. In patients with these mid-range IAP's, we often observed dramatic reductions in ICP following abdominal decompression. Our practice led us to be increasingly vigilant, routinely measuring IAP every several hours in all patients with severe TBI, particularly those with borderline ICP's. Our willingness to decompress the abdomen increased.

One should not underestimate the consequences of an open abdomen. Patients often lost liters of fluid per day in the vacuum dressings we used in such patients. We rarely were able to achieve primary fascial closure. These patients often ended up with split thickness skin graft on the abdominal wall, ventral hernias, and a 15% incidence of the dreaded complication of entero-atmospheric fistula formation. We were willing to except these complications because the patient was alive to have them. In recent years, the incidence of MCS has certainly dramatically decreased. We no longer use large volume crystalloid resuscitation instead relying on earlier use of blood and blood products. The so-called Damage Control Resuscitation has limited the incidence of visceral edema, ACS, and subsequent MCS. However, the incidence is not zero. Clinicians who care for serious injury must keep this in mind. Occasionally, abdominal decompression to reduce ICP is still needed.

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Is There an Optimal Screening Tool to Best Diagnose and Treat Blunt Cerebrovascular Injury (BCVI)?

18

Paramita Das

Introduction

Blunt cerebrovascular injury (BCVI) is a rare complication of trauma. It can result in vessel dissection or pseudoaneurysm formation intracranially or in the neck. Although uncommon when missed it carries a risk of ischemic stroke.

BCVI is caused by a trauma where there is neck flexion, extension, and/or rotational trauma as a result of high acceleration–deceleration force [1]. The force causes a tear in the intima of the vessel wall and the blood dissects into the vessel wall at the site of the defect and can propagate in the direction of the blood flow [2]. The injury to the intima exposes the blood to the thrombogenic subendothelial extracellular matrix.

Overall blunt cerebrovascular injuries are fairly rare but within trauma patient with higher injury scores the incidence can be as high as 2.7% [3]. Untreated BCVI is associated with stroke in 30–40% of patients with carotid artery injuries and in 10–15% with vertebral artery injuries [2]. Approximately 60% of strokes occur within 3 days of injury and over 85% by 7 days with fewer than half exhibiting neurological symptoms prior to arrival in the hospital [4].

Search Strategy

A search was conducted in the PubMed database for articles in the English language using the search term "blunt cerebrovascular injury." Only articles available as full text were included. The available articles were listed from 1987 to 2020. The references for these articles were reviewed for any additional pertinent resources.

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Screening Tools

Controversy exists regarding BCVI screening due to the severity of the sequelae when these injuries are missed. Table 18.1 demonstrates the inclusion criteria for patients that should be screened. If undiagnosed and untreated BCVI can have stroke and mortality rates up to 25% [5–9]. The Denver screening tool, first proposed in 1999 by Biffl et al., became the BCVI protocol most commonly used for those that are at risk for BCVI [10]. It was then expanded in 2011 to include markers of high force such as mandible fractures, skull fractures, traumatic brain injury, scalp degloving, thoracic vascular injuries, and upper rib fractures [11]. The expanded protocol has a reported sensitivity of 82.5% and also moderate specificity at 50%, respectively [12, 13]. The Memphis screening tool [14] is similar to the Denver screening tool, however, the expanded Denver criteria are still the best studied and most supported by recent best practice guidelines [15]. The Denver criteria also include all indicators applied by the Memphis screening tool [16, 17]. Despite the endorsement of consensus groups such as the Eastern Association for the Surgery of Trauma (EAST) and the Western Trauma Association (WTA), a BCVI screening protocol is not uniform across all practices [18]. In a series of 236 patients with BCVI, 5% of the BCVI injuries did not fit into the expanded Denver screening criteria advocating for keen clinical acumen when deciding on when to screen patients [19]. Widespread screening of all traumas without some selection criteria is not thought to be the best avenue for BCVI detection.

Table 18.1 Expanded Denver criteria: Clinical findings and associated injuries which should lead one to screen for BCVI

Signs of BCVI	Risk factors for BCVI
Arterial hemorrhage from neck, nose, or mouth	High energy transfer mechanism
Cervical bruit in patients <50 years old	Lefort II or III
Expanding cervical hematoma	Mandible fracture
Focal neurological deficit (TIA, hemiparesis, vertebrobasilar symptoms, Horner's syndrome)	Complex skull fracture/basilar skull fracture, occipital condyle fracture)
	Cervical spine fracture, subluxation, or ligamentous injury
Stroke on CT or MRI	Severe TBI with GCS < 6
Neurological deficit inconsistent with head CT	Near hanging with anoxia
	Clothesline type injury or seat belt abrasian with significant swelling, pain, or altered mental status
	Scalp degloving
	Blunt cardiac Rupture
	Upper rib fracture

Computed Tomography Angiography (CTA)

Although CTA imaging is a noninvasive option there are monetary costs to the intervention, a risk of radiation, and also intravenous contrast administration [20]. Guidelines from both the EAST and WTA were published indicating that 16 slice or greater CTAs may be acceptable screening modalities [21, 22]. CT is also preferred as there are usually other regions of the body being scanned with CT for a poly trauma patient. MR angiography historically has poor sensitivity and specificity for BCVI detection measuring 50–75% sensitivity and 67% specificity making it inferior to CT angiography which has sensitivity of 66–98% and specificity of 92–100% [23]. The sensitivity and specificity of the CTA is also dependent on the experience of the radiologist and the quality of the imaging [24]. CTA may detect all clinically significant BCVIs as very few strokes have been observed in trauma patients with a negative CTA [15]. After the initial imaging shows concern for injury there are many groups that advocate for reimaging in 7 days due to possible misinterpretation of CTA due to vessel spasm [21, 22].

Duplex Ultrasound

Duplex ultrasound is used for monitoring extracranial carotid artery atherosclerotic disease but is not recommended for use in trauma. It can miss lesions at the base of the skull due to bony artifact. A large series of trauma patients reported the sensitivity of ultrasound was just 39% [3].

Four Vessel Arteriography

Four vessel arteriography is the gold standard imaging study to diagnose BCVI's. However, four vessel arteriography is more invasive and is associated with complications such as dissection, and thromboembolism [25]. In clinical practice it is more commonly used for those with clinically indeterminate cases, or those that may need potential intervention.

Diagnosis of BCVI

The most widely used grading scale for these vascular injuries is the Denver scale (also referred to as the Biffl scale). This grades the lesion from one to five with increasing grades corresponding to more severe injuries [26]. Grade I injury is defined as any vessel wall irregularity, dissection, or intramural hematoma with less than 25% stenosis. Grade II injury is defined as a dissection or intramural hematoma with greater than 25% stenosis. Any injury with a raised intimal flap, or intraluminal thrombus is also classified as grade II. Grade III injury is a traumatic

pseudoaneurysm. Grade IV injury is a complete vessel occlusion. Grade V is defined as arterial transection or arteriovenous fistula formation. Grade V injuries are much more commonly seen with penetrating injuries.

Treatment

Aggressive screening protocols and the early institution of antithrombotic therapy have reduced the BCVI related stroke rate from 20% to less than 1% in patients receiving treatment [9, 11]. Grade I, II, III, and IV injuries are all treated with antithrombotic therapy. Grade IV injuries often stay on therapy lifelong to reduce their stroke risk. Grade V injuries are treated endovascularly or with open surgery [2]. Intracranial dissecting aneurysms are treated more aggressively due to the possibility of subarachnoid hemorrhage.

There are no prospective randomized controlled trials to definitively guide treatment in blunt cerebrovascular injury, and there is variability in practice on the selected treatment. Retrospective trials exist which show improved outcomes with antithrombotic therapy. A survey of 785 US clinicians found providers divided between favoring anticoagulation (42.8%), antiplatelet agents (32.5%), or both (17.1%) [27]. The CADISS trial group found no difference in efficacy of antiplatelet and anticoagulant drugs for the prevention of recurrent stroke after symptomatic carotid and vertebral artery dissections [28]. Another more recent literature review and review of 370 patients found similar results [29]. There are two studies which found lower proportions of bleeding complications with antiplatelet agents compared to anticoagulation agents [30, 31]. Occasionally there are instances where antiplatelet therapy is held due to other injuries and the concern for hemorrhage. A study looking at 31 patients who had BCVI who did not have antiplatelet therapy due to other injuries had a stroke rate of 45% [15].

One of the instances where antiplatelet therapy is often withheld is when the patient has a concurrent traumatic neurologic injury with a BCVI. A 10-year single center retrospective review looking at treatment in those with concurrent BCVI and traumatic neurologic injury showed no difference in rates of hemorrhagic deterioration between those treated versus those not treated [32]. Unfortunately the specifics of the traumatic neurologic injuries were not closely examined and because of the retrospective nature, the patients were not randomized for treatment. Currently, the timing of treatment in those with concomitant hemorrhagic neurologic injury continues to remain provider dependent without strong guidelines.

The length of treatment is also variable as a strong recommendations have not been made by any guidelines in regard to BCVI treatment [15]. In a study of 110 patients with blunt carotid injuries, angiographic follow up at a mean of 6 months was available in 50 patients demonstrating stable or improved findings in 75% of cases [31]. Franz et al. reimaged 17 of 29 patients with BCVI with complete resolution in 84% at a mean of 9.2 weeks [33]. These few studies are the reason why many advocate for reimaging at 3–6 months. On follow-up imaging if there is resolution of the finding antiplatelet/and or anticoagulation may be stopped. There are reports

of luminal recovery even up to 1 year and therefore if there is continued abnormality then repeat imaging may be advocated. If there is not recovery, then persistent stenosis from the dissection may be addressed similar to the management of atherosclerotic stenosis [34].

Endovascular and surgical treatments are dependent on the grade of injury and the efficacy of the medical therapy. Stenting for traumatic carotid artery dissections is occasionally performed. Stent placement requires dual antiplatelet coverage and in trauma patients this can be problematic. This is only considered when there are continued thrombotic events even with medical therapy. Traumatic extracranial dissecting aneurysms usually resolve spontaneously, and these aneurysms are rarely symptomatic [27]. However, there can be rare instances when endovascular treatment is strongly considered, such as for pseudoaneurysms progressing in size or severe luminal stenosis causing thrombotic or ischemic events even with medical therapy. There are other complications including stent occlusion which can result in further ischemic events which makes the decision to intervene a significant one [35].

In full vessel occlusion there has been no data to show benefit of surgical or endovascular treatment, although there are some centers that advocate that these vessels should be embolized to prevent ischemic events if the artery recanalizes [36]. This has not been studied rigorously and more recently providers favor expectant management with antiplatelet therapy alone. This is favored as it has been reported there can be recanalization in those that have poor collaterals and are treated with medical therapy [37]. This may prevent delayed ischemic events. For these patients it may be best to follow up their vascular imaging to see if there is recanalization and assess any thrombotic risk at that time.

In a grade V injury where there is active bleeding or signs of major vascular injury, surgical or endovascular treatment must be emergently considered. If there is an expanding neck hematoma, direct pressure should be applied until intervention can be performed. If there is bleeding from the mouth, ear or nose surgical ligation or embolization can be performed [2].

Recommendation Based Upon the Data

BCVI usually presents without any neurologic symptoms and therefore its diagnosis on initial presentation is paramount. When left untreated there is a higher incidence of ischemic stroke which can have significant morbidity and mortality. CT angiogram is the study of choice for screening of these patients. Treatment with antiplatelet agents over anticoagulants may be preferred not due to their stroke risk reduction but do the antiplatelet agents possibly having a lower proportion of bleeding complications. If patients continue to have thrombotic events with medical therapy, endovascular treatment may be considered. If there is active bleeding or vessel transection, emergent surgery or endovascular treatment is indicated. Even with the widespread incidence of these injuries the ideal treatment and length of treatment continue to remain unclear. What is clear from the review of the evidence is that early treatment prevents ischemic strokes.

Summary of Recommendations

- The expanded Denver criteria are still the best studied and most supported by recent best practice guidelines (evidence quality moderate; strong recommendation).
- Widespread BCVI screening of all traumas without some selection criteria is not thought to be the best avenue for BCVI detection (evidence quality moderate; strong recommendation).
- The length of treatment is variable and many advocate for reimaging at 3–6 months (evidence quality low; weak recommendation).

Personal View of the Data

Using a systematic method of screening patients such as the expanded Denver criteria we are able to find more BCVI's than when using clinical acumen alone. However, both clinical acumen and the screening criteria should be used in combination to find BCVI as early as possible during work up. CT angiography is the study of choice and angiography is rarely needed for evaluation. Once diagnosed antiplatelet therapy should be initiated for Grade I, II, III, and IV. Grade V injuries are treated with endovascular or surgical intervention. Antiplatelet is preferred over anticoagulation due to lower reported bleeding complications. Our general practice is that follow up for these patients can be performed at 3 months, and if there is still concern of dissection which may result in stroke, then a repeat imaging study is performed at 6 months. Antiplatelet therapy is continued during this time period.

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Part VI

Abdominal Trauma

Does Specific Sequencing of Operative Interventions in Thoracoabdominal Trauma Improve Outcomes?

19

W. Ian McKinley and Priya S. Prakash

Introduction

Thoracoabdominal trauma has long vexed even the most experienced and clinically skilled surgeon. By definition, it can involve multiple body cavities and injuries to many major organs which threaten the life of the patient; this involvement has historically been referred to as "double jeopardy" which reminds the reader of the increased risk for multicavitary injury [1]. It should also remind the reader of the concern for diaphragmatic injury which is the hallmark of thoracoabdominal trauma and can further complicate the decision-making process.

Attempts to study this topic have been hampered by multiple factors; outside of high-volume trauma centers, these injuries are relatively rare. Additionally, they span the spectrum of heterogeneity, ranging from injuries amenable to nonoperative management to more complex injury patterns involving both cavities, major vascular structures, and multiple organ systems. Even within the same degree of injury to the patient, mechanism of injury plays a large role in the character of internal damage that occurs; a stab wound with its low kinetic energy cannot be easily compared with a gunshot wound and the ballistic injury it causes on top of the penetrating injury [2].

Guidelines from the ATLS program have standardized the workup of trauma patients and prioritized life-threatening injuries, while research continues to identify practice changes to enhance outcomes. For stable patients, the advent of and

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subsequent improvements in computed tomography produce sufficiently detailed information to rule in or out injury in most organ systems with a high degree of confidence [3, 4]. Similarly, ultrasound at the bedside now allows for high-quality imaging with the focused assessment with sonography in trauma (FAST) exam leading to rapid identification of patients with intra-thoracic or intra-abdominal problems requiring surgical intervention [5].

These advancements have certainly assisted in the care of countless patients, yet rapid assessment and surgical management of these complex patients remain a challenge due to various factors. What is the surgeon to do when the patient cannot undergo such a workup? What is one to do for the patient requiring care in an austere setting, or the unstable and hypotensive patient who otherwise would not survive radiological workup? The simple answer of "go to the OR" is insufficient; blindly probing at body cavities increases both morbidity and mortality while failing to serve the patient by progressing towards definitive control of injuries in an expeditious fashion [6]. It is this conundrum with which surgeons are often faced: where is the injury of greatest severity? With limited time in which to make a decision and with little information available, the surgeon must find a way to proceed forward while making as few mistakes as possible lest the patient suffer a demise which otherwise may have been avoided. The purpose of this review is to formally elucidate the correct sequence of surgical interventions for trauma patients presenting with hypotension and thoracoabdominal injuries.

Search Strategy

A literature search of English language publications from 1978 to 2019 was used to identify published data on thoracoabdominal trauma sequencing. Databases searched were PubMed, PubMed Central, and MEDLINE. Terms used in the search were "double jeopardy," "thoracoabdominal trauma," "thoracoabdominal," and "trauma." Studies were excluded if they focused only on thoracic or abdominal trauma, or if they did not provide information regarding their studied population or other relevant clinical information. The included studies were evaluated using the GRADE system. Our clinical review of appropriate cavitary triage for penetrating thoracoabdominal trauma is categorized in Table 19.1.

Table 19.1 P-Penetrating thoracoabdominal trauma prioritization, I-Thoracotomy, tube thoracostomy, FAST, Exploratory laparotomy, C-Exploratory laparotomy before thoracotomy/median sternotomy, Thoracotomy/median sternotomy before exploratory laparotomy, and O-Mortality, morbidity

P	I	C	O
Penetrating thoracoabdominal trauma prioritization	Tube thoracostomy Thoracotomy FAST Exploratory laparotomy	Exploratory laparotomy before thoracotomy/median sternotomy Thoracotomy/median sternotomy before exploratory laparotomy	Morbidity Mortality

Results

A total of eight studies [2, 5, 7–12] regarding the sequencing of thoracoabdominal trauma patients were identified. There were no randomized studies, and all were retrospective. All were at high risk for bias given their retrospective nature and use of limited populations, and the majority of the studies either did not address at least one important piece of clinical information or had the same data for multiple clinical outcomes due to their small population size.

A critical review of the literature did not provide data for comparison of the possible means of operative decision making. Instead, we assessed the data for relevance to clinical practice in order to draw the best possible conclusion based on the available information.

Presentation and Diagnosis

Having been described as a situation of "double jeopardy," concomitant traumatic injury to both the abdominal and thoracic cavity remains a challenging clinical scenario for many surgeons due to the variability in presentation, unreliable physical exam findings, and limitations to diagnostic modalities. The clinical complexity of these situations is further compounded by continued debate on optimal management strategies, diagnostic workup, and surgical sequencing. In addition, blunt versus penetrating thoracoabdominal trauma lends further nuances in initial assessment and management strategies centered on underlying kinetics associated with the mechanism of injury, amenability to nonoperative management, and associated injury patterns.

It is important to understand the anatomical borders defining the thoracoabdominal region in order to identify, evaluate, and manage potential traumatic injuries. The upper border is defined from the fourth intercostal space in the mid-clavicular line anteriorly, the sixth intercostal space laterally in the mid-axillary line, and the eighth intercostal space along the mid-scapular line. The lower border is defined by the sub-costal margin, with the sternum and vertebral bodies forming the anterior and posterior borders, respectively. Trauma to this region of the body should prompt the surgeon to suspect injuries involving both cavities as many intra-abdominal organs are within the region of the lower chest.

Mechanism of injury and patient physiology should also be taken into consideration to guide prioritization of diagnostic and therapeutic interventions as the variability in kinetic energy associated with blunt versus penetrating trauma and with firearm versus non-firearm injuries lends itself to differing injury patterns and management strategies. The majority of blunt thoracoabdominal trauma in the hemodynamically stable patient can be managed nonoperatively with expectant management

for both abdominal solid organs and thoracic injury [7]. The need for combined thoracoabdominal operations is rare in these patients, with the majority of injuries requiring operative intervention found within the abdomen making the abdomen the initial cavity of exploration in most cases [12].

Penetrating thoracoabdominal trauma can present in a variety of ways, and initial management strategies are often dictated by patient acuity and potential trajectory of the penetrating mechanism, especially in patients presenting with gunshot wounds. Gunshot wounds to the thoracic cavity have been associated with abdominal injuries in 30–40% of patients, with the liver, spleen, and stomach being the most commonly injured intra-abdominal organs in penetrating thoracoabdominal trauma [13]. A combined approach with both thoracotomy and laparotomy due to hemorrhage above and below the diaphragm has been reported in approximately 2% to 6% of patients with penetrating thoracic trauma [14–17]. Hirshberg et al. reported that one third of patients who required both thoracic and abdominal explorations underwent aborted procedures of the initial cavity due to ongoing hemorrhage from the opposite side of the diaphragm, emphasizing the difficulties and pitfalls associated with the sequencing of cavitary exploration in penetrating thoracoabdominal trauma [9].

The initial workup of the trauma patient presenting with thoracoabdominal trauma should be guided by ATLS. In this patient population, there should be a high degree of consideration for rearrangement of the usual "ABC" order of operations to "CAB," especially when there is a high degree of concern for cardiac injury causing pericardial tamponade. If this concern is present, the patient should be taken directly to the OR with blood products available and the surgeon prepared to proceed with sternotomy. In other patients, the workup should proceed in the usual fashion. Adjunctive studies should not be unnecessarily pursued with concern that the time they consume delays hemorrhage control. The surgeon should additionally consider ways in which these studies may lead them "astray" (e.g., pericardial tamponade that decompresses into the abdomen or thoracic cavity) and consider abandoning pursuit of further workup in favor of proceeding to the operating room with the best available information.

Patients who are hemodynamically stable without respiratory distress should undergo a chest radiograph to assist in evaluation of thoracic injuries and potential trajectory of penetrating wounds. In the alert patient without neurologic deficit or hemodynamic compromise, abdominal examination is usually reliable in assessing the need for abdominal exploration. Patients who present with associated injuries or conditions that limit the reliability of physical exam, such as those with traumatic brain injuries, other distracting injuries or intoxication may warrant additional diagnostic studies such as ultrasonography, computed tomography, local wound exploration, or laparoscopy to assist with diagnosis of injuries.

For patients who present with hemodynamic instability, physical examination and expedited cavitary triage with chest and/or pelvic radiography and bedside ultrasonography can guide the clinician in which cavity to operatively approach initially. Though approximately 85% of patients with thoracic trauma can be managed with observation or tube thoracostomy, the subsequent decision to perform a

thoracotomy should be based on the patient's hemodynamic status, response to blood product resuscitation, concern for cardiac tamponade, initial tube thoracostomy output and rate of hemorrhage, or radiographic evidence of great vessel or tracheobronchial injury [15]. If a major cardiovascular injury or cardiac tamponade is suspected, then the patient should be taken emergently to the operating room for exploration of the thoracic cavity with either thoracotomy or sternotomy. For the remainder of patients, initial drainage of 1000 mL to 1500 mL after tube thoracostomy placement has traditionally been used as an indication to proceed with thoracotomy. Demetriades et al. challenged framing thoracic interventions based upon 1000–1500 mL believing that tube thoracostomy output could be misleading and challenged its role in operative decision making [18].

When assessing the need for abdominal exploration, indications to proceed with operative intervention include abdominal tenderness away from the site of penetrating injury or diffuse peritonitis, hypotension, or continued hemorrhage. Bedside ultrasonography has become an important adjunct to the initial evaluation of the trauma patient that may assist in the decision to proceed with operative exploration. Given its high sensitivity and specificity in evaluating precordial wounds as well as hypotensive patients with blunt torso trauma, a positive ultrasound exam often supports the decision to proceed with surgical intervention [19]. But the clinician should remember that concomitant thoracic trauma in these patients may decrease sensitivity of the abdominal examination and associated diaphragmatic injuries may result in misinterpretation of tube thoracostomy drainage and assessment of intra-abdominal injuries with bedside ultrasound further complicating the evaluation of the patient presenting after thoracoabdominal trauma [1, 8, 20].

Recommendations Based on the Data

Once the decision to proceed to the operating room has been made, the best available information should be utilized in order to determine which cavity houses the most significant injury in order to avoid delayed treatment and increased morbidity and mortality [10]. Special attention should be paid to the exterior physical exam, noting the areas of injury and, in the setting of penetrating injury, attempting to understand the possible trajectories of the projectile. The operation should begin with accessing the most likely cavity of injury, with attempts to gain control of the life-threatening injury as quickly as possible. This seems trite, but it is easy to end up with tunnel vision and overlook exam findings that can guide the operation. Some authors have advocated for a "laparotomy first" or a "thoracotomy first" approach; this is an approach that risks leading to the surgeon failing to acknowledge the information in front of them and surgeons should avoid this degree of rigidity in their thinking. All reasonable attempts should be made to avoid entering cavities unnecessarily to decrease the risk of hypothermia and secondary coagulopathy. Control of injuries should be gained in the usual fashions; these techniques have been described elsewhere and are outside of the aim of this chapter.

Thoracoabdominal trauma can present in a variety of ways and with a number of associated injuries above and below the diaphragm. Surgeons should be aware of the unreliable physical exam findings, misleading tube thoracostomy output, and decreased sensitivity of ultrasound in the presence of hemothorax or diaphragm injury in these patients. Though many blunt injuries can be managed nonoperatively, the unstable patient and those presenting with a penetrating mechanism often need operative intervention. There are no conclusive studies on what should be the standard surgical approach to operative management in these complex patients. Rather, the surgeon must rely on a high index of suspicion for a variety of life-threatening injuries and employ a clinical acumen to guide decision making.

Summary of Recommendations

- Initial cavitary triage with eFAST, chest radiography, and tube thoracostomy during the primary survey of a patient with thoracoabdominal trauma can determine the sequence of interventions in the operating room (moderate quality of evidence, strong recommendation).
- Patients with penetrating thoracoabdominal trauma with a positive cardiac FAST should undergo sternotomy first in the operating room (moderate quality of evidence, strong recommendation).
- Patients with penetrating thoracoabdominal trauma who have a negative chest radiograph and positive abdominal FAST should undergo laparotomy first (low quality of evidence, strong recommendation).
- Patients with penetrating thoracoabdominal trauma who have high tube thoracostomy output or large retained hemothorax on chest radiography after tube thoracostomy placement and a negative abdominal FAST should undergo thoracotomy first (low quality of evidence, strong recommendation).
- In hemodynamically stable patients with blunt or penetrating thoracoabdominal trauma, computed tomography imaging should be considered to assist with evaluation of thoracic and abdominal injuries and need for operative intervention (moderate quality of evidence, strong recommendation).
- In hemodynamically unstable patients, with a positive chest radiograph and high chest tube output as well as a positive abdominal FAST, determining trajectory, most likely injured structures that require emergent intervention, and the surgeon's clinical acumen should guide operative sequencing in thoracoabdominal trauma (no evidence, strong recommendation).

A Personal View of the Data

There is a paucity of data to support decision making for which cavity should be explored first. The dilemma is unsurprising given the difficulty that must occur in attempting anything beyond a retrospective look at the data with such a heterogenous population of patients. There is a high risk for bias and the majority of the

reviews do not address at least one important piece of clinical information or had the same data for multiple clinical outcomes due to their small population size.

Before proceeding with any operative intervention, the surgeon should always keep in the back of her mind what she will do to "bail out" and how each incision or maneuver affects that possibility. A surgeon must be cognizant of the ongoing resuscitation of a patient in the operating room and the need to proceed with damage control maneuvers for the patient in extremis. Injured vessels should be ligated or shunted instead of definitively repaired in such a tenuous setting, and other principles of damage control should be maintained.

It must be stated that an attentive trauma surgeon should be aware of all potential pitfalls and incorrect sequencing events and allow for flexibility to redirect operative exploration if the initial approach does not appropriately stabilize the patient.

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Selective Non-operative Management for Abdominal Gunshot Wounds

20

Lindsey Karavites and Kenji Inaba

Introduction

Given that the abdomen is a cavity with the potential to hide life-threatening injuries, paired with the often-unpredictable pattern of bullet trajectory, the management of abdominal GSWs has historically mandated surgical exploration to safely treat or definitively rule out injury. Realizing that mandatory exploration leaves a subset of the population with a non-therapeutic laparotomy, a procedure that carries morbidity rates as high as 20%, it is important to spare patients if at all possible [1]. Due in large part to advances in imaging technology and accessibility, the paradigm has shifted toward non-operative management in select patient populations. However, because SNOM of abdominal GSWs is not universally practiced at this time, it is worthwhile to review the existing evidence and discuss the barriers to broader acceptance among trauma surgeons tasked with managing such wounds. Finding a balance between prompt surgical interventions when indicated, while avoiding the morbidity of an unnecessary procedure, remains challenging in this setting. Management decisions are straightforward when there is a hard sign to go to the operating room. In absence of peritonitis, hemodynamic instability or factors complicating physical exam, such as a depressed level of consciousness, the decision becomes much more complex. Additionally, the overall incidence of penetrating abdominal injuries has declined over the past few decades. According to the Spring 2019 Trauma Quality Improvement Program, among the 300,000 patients entered, firearm injuries represented only 3.2% of all traumas. This reduction in cases has resulted in decreased experience with managing these wounds among providers at many trauma centers further complicating this decision-making process. Reviewing the most recent evidence on this evolving topic is important to

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increasing universal acceptance. Successful implementation of SNOM for those with abdominal GSWs has the potential to reduce the morbidity related to a non-therapeutic laparotomy, reduce overall hospital cost, and shorten hospital length of stay. Physical exam and diagnostic imaging are central to the safety and efficacy of this process. For abdominal GSWs, adjuncts such as local wound exploration and diagnostic peritoneal lavage are not routinely practiced. CT, however, is a critical step in the evaluation of stable patients who have sustained GSWs to the abdomen. We have chosen to explore the most recent evidence regarding the diagnostic accuracy of CT in the setting of abdominal GSWs to determine missile trajectory, internal injury burden and to identify those patients who can safely be selected for non-operative management. We will then review the data establishing the important role of serial physical examinations in this process as well as the latest evidence on the safety and efficacy of SNOM as a whole in the setting of abdominal GSWs. Finally, we will offer our personal experience with SNOM and provide our best recommendations for decision-making in areas where lack of consensus on this topic exist.

Search Strategy

English language publications from 2000–2019 were searched in PubMed, Ovid, Medline, and Cochrane Evidence Based Medicine Databases to identify published data on SNOM of abdominal GSWs and the diagnostic accuracy of CT imaging in guiding patient selection in this setting to optimize outcomes. We used the *PICO* process to generate our clinical research question. The model displayed in Box 20.1 includes our selected *P*atient population, *I*ntervention, *C*omparator, and *O*utcome constructed to better structure our query. Using the terms "penetrating abdominal trauma" AND "abdominal GSW" AND "selective nonoperative management" AND "CT scan" AND "intraoperative complications" OR "perioperative complications" OR "postoperative complications" OR "mortality" OR "overall cost" OR "hospital length of stay" items were sorted based on relevance. Articles were excluded if all data analyzed were pooled to include all types of penetrating abdominal wounds and articles that had missing information regarding imaging used. Individual study types were listed in Table 20.1. No randomized controlled trials are available. The data were classified using the GRADE system. Strength of recommendations was based on the quality of evidence reviewed.

Box 20.1 PICO Search Strategy

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with abdominal GSW	SNOM with mandatory CT scan	Routine operative Mgmt (OM)	Mortality, complications, diagnostic accuracy of CT, length of stay

Table 20.1 Evidence and recommendations on the components of SNOM algorithm[a]

Controversial issue	Number of studies reviewed	Quality of evidence	Recommendation	Grade of recommendation
Patient selection	16	Moderate	Patients must be stable, evaluable, and without peritonitis	Strong
Diagnostic accuracy of CT	6	Moderate	CT sensitivity and specificity is higher for clinically significant injuries	Moderate
Mandatory vs. selective CT	4	Moderate	CT should be performed for all patients undergoing trial of SNOM	Moderate
Type of CT	12	Low	CT with IV contrast	Weak
Duration of observation period	7	Low	24 h	Weak
Serial Abd exams by surgeon	2	Moderate	Serial exams by experienced provider are mandatory, ideally same provider	Strong
Safety of SNOM	11	Moderate	SNOM is a safe management option	Strong
SNOM at low volume centers	2	Low	SNOM is a safe option at low volume centers	Weak

[a]Several studies were applicable to more than one controversial issue

Results

The data available were reviewed to assist in standardization of the process of SNOM and to evaluate the safety and efficacy of this practice in reducing morbidity, costs, and in improving outcomes in the management of abdominal GSWs. The diagnostic accuracy of CT scan for GSWs was also reviewed with a goal of arriving at a more widely accepted consensus to scan all stable patients as part of the selection process for those best suited for SNOM. In keeping with our search strategy, penetrating mechanisms other than injury from a firearm will not be discussed in this chapter. Additionally, as we incorporate our recommendations, it is important to understand that there have not been, nor is it likely that there ever will be, randomized controlled trials to evaluate the outcomes of SNOM versus mandatory laparotomy for the management of abdominal GSWs.

Patient Selection

Beginning in the 1960s with stab wounds, followed by GSWs, the historical paradigm of exploring all patients with penetrating abdominal wounds began to shift toward non-operative management in a subset of patients [2–4]. Selection for operative versus non-operative management based on the clinical picture and radiologic evidence began to evolve in an attempt to balance prompt surgical management with avoiding an unnecessary operation. Patients who present in extremis, with hemodynamic instability, peritonitis, or are unevaluable, mandate immediate operation. For the remaining patients, the practice of universal exploration would result in a high rate of non-therapeutic laparotomy. Although mortality after negative trauma laparotomy is low, the morbidity attributed to negative laparotomy is as high as 20% [5, 6]. In addition, late complications including hernias and bowel obstructions are likely underreported given the challenges of long-term follow-up in this population. Although GSWs to the abdomen are more likely to require operative exploration, the presence of a gunshot injury alone does not necessitate mandatory laparotomy. In an analysis of 1856 patients with abdominal GSWs, had a policy of mandatory laparotomy been employed, 47% of patients would have undergone an unnecessary laparotomy [7]. Further, mandatory laparotomy in patients with abdominal GSWs has been linked to a 22–41% risk of postoperative complications such as surgical site infections, gastrointestinal ileus, pneumonia, and venous thromboembolism [8, 9] and a 5- to 9-day length of hospital stay [10–12].

In the modern era of SNOM for penetrating abdominal trauma, several absolute indications for operative intervention remain. Hemodynamic instability requires laparotomy. In the hemodynamically stable patient, physical examination remains critical to patient triage, and peritonitis is an absolute indication for surgical intervention. Although soft tissue injury can cause local tenderness, diffuse peritonitis after penetrating abdominal trauma is associated with a 97% chance of intra-abdominal injury at laparotomy [13]. Given the central role of physical examination in patient triage, unevaluable patients including those with concomitant head or spinal cord injury or those undergoing urgent non-abdominal operations are not candidates for SNOM. Patients with omental or visceral evisceration after penetrating abdominal trauma should be strongly considered for operative intervention, however, it is not considered an absolute contraindication to SNOM. Significant intra-abdominal injury is present in 46% to 85% of patients with omental evisceration, and rates are even higher with visceral evisceration [14–17]. Peritoneal penetration alone after penetrating trauma does not mandate exploration nor is it necessary to perform diagnostic laparoscopy for the sole purpose of determining the presence or absence of peritoneal violation. Once those with hard indications for laparotomy are identified, the remaining patients should be considered for SNOM. CT is the next step and serves as an essential component of the diagnostic workup of these patients. In hemodynamically stable patients without peritonitis and no barriers to physical exam, a detailed evaluation of the external wounds, retained fragments, and an estimation of internal injury burden with plain films is imperative to plot missile trajectory. External wounds do not always correspond to

internal injury and, especially in the setting of multiple missiles; trajectory may be misleading from external wounds alone. Management will change significantly based on the internal trajectory. For this reason, we believe CT to not only be the next step in our management algorithm, but also critical to the success of SNOM.

Importance of Imaging

The use of CT in diagnosing injuries in stable patients with abdominal gunshot wounds is widely accepted and much more so than with other types of penetrating abdominal trauma. Because GSWs tend to follow a linear path with an associated air bubble tract, trajectory of the bullet is easier to determine than that of a stab wound. Understanding the missile trajectory provides critical information regarding potentially injured structures and those for which injury is unlikely. CT imaging after abdominal GSWs has been shown to be highly reliable for injury identification, with a sensitivity and specificity of 90.5% to 96% and 95% to 96%, respectively [18, 19]. The diagnostic accuracy of CT in this setting has been established over the past few decades. Melo prospectively reviewed a large group of patients with abdominal GSWs undergoing laparotomy to compare operative findings to multi-detector row CT findings. Images were evaluated by two radiologists for evidence of injury to solid and hollow organs, vascular structures, urinary bladder, diaphragm, fractures, and general findings (free fluid, pneumoperitoneum, and mesentery lesions). No statistically significant differences between radiologists were found. All of the solid and hollow organ injuries, vascular lesions, and general findings were detected [20].

For patients undergoing urgent exploration, CT is unnecessary and should not be routinely obtained. However, given the diagnostic accuracy of CT scan in the setting of abdominal GSWs, it is logical to consider the imaging modality as the requisite next step in evaluating those who are stable, examinable, and without peritonitis to distinguish those who require immediate laparotomy from those who qualify for a trial of SNOM. CT may then be used to alert the provider to injuries requiring intervention in those who have not yet developed symptoms. In addition to exposing missile trajectory, CT also carries the theoretical advantage of shorter time to intervention in those with CT identified injuries and earlier hospital discharge in those with negative scans. The added value of routine CT scan in this cohort has been demonstrated in multiple systematic reviews because imaging offers higher sensitivity and specificity versus clinical examination alone in detecting injuries and assists in reducing the risk of failure of SNOM [1, 21, 22]. Although several studies report selective use of CT scan for SNOM with variable results, we, in alignment with the Western Trauma Association Algorithm, recommend that all patients selected for SNOM undergo a high-quality CT scan of the abdomen and pelvis (with addition of chest CT for upper abdominal/thoraco-abdominal injuries) that is immediately reviewed by both the trauma surgeon and trauma radiologist prior to the clinical observation period [23]. For GSWs, in a recent prospective evaluation of SNOM, approximately 53% met criteria for SNOM and underwent CT [24]. Among

these patients, approximately 30% had an injury identified on CT necessitating an operation. All who underwent exploration based on CT findings had a clinically significant intra-abdominal injury. Further, 34% had negative imaging and could be safely discharged home without laparotomy. The remaining 36% of this group, with equivocal CT scans required observation [24, 25]. Therefore, in this population, CT directly impacted clinical management, effectively delineating those who required an operation from those who could be sent home and those who required observation. In addition, a 2018 meta-analysis reviewing outcomes in those undergoing SNOM for abdominal GSWs concluded that the mandatory use of abdomino-pelvic CT was associated with a failure rate of SNOM that was approximately half of that reported for selective use of CT scanning. These findings suggest that use of CT may confer a higher degree of confidence to surgeons managing patients with equivocal exam findings or concerning missile trajectories [21].

After establishing CT to be the next step in this process, is the type of CT performed an important distinction? Significant discussion and debate remain regarding the type of contrast CT used in this setting for optimal diagnostic accuracy as well as timely diagnosis of injury. Some argue for the addition of oral and rectal contrast ("triple contrast") to increase the sensitivity for key structures such as the retroperitoneal duodenum or colon. Triple-contrast CT scan has been reported to have sensitivity of 100%, specificity of 96% to 100%, and accuracy of 98% in identifying operative injuries after penetrating abdominal trauma [26–28]. However, others have reported similar results without the addition of enteral contrast [22, 29–31]. In the setting of penetrating trauma, even short delays in the diagnosis of colonic and rectal injuries have been more clearly associated with increased morbidity and mortality, likely due to the increased incidence of fecal peritonitis, sepsis, or both [32–34]. Huynh et al. found that routine use of oral contrast material with CT in patients presenting to the emergency department can delay the registration-to-disposition time by 173 min [35]. A study by Jawad showed single-contrast CT to have overall sensitivity of 88% and specificity of 72% in detecting bowel injuries in the setting of penetrating abdomino-pelvic trauma which is comparable with that reported for triple-contrast CT. These outcomes underscore the value of trajectory mapping and surrogate signs used to identify bowel injury in the absence of the overt leaking of contrast from the injured bowel. These signs include disruption of the bowel wall or bullet fragments in the bowel, bowel wall thickening, penetrating wound tract leading to the bowel, or bullet fragments abutting the bowel wall [36]. We recommend a high-quality CT scan with IV contrast as the standard study to be obtained initially, with the addition of oral or rectal contrast at the discretion of the attending surgeon and radiologist for any areas requiring further delineation.

Importance of the Observation Period

Despite our confidence in the diagnostic accuracy of CT scan in this setting and our recommendation that its use is a critical component to successful SNOM, we would be remiss to ignore the fact that it is not a stand-alone tool in this process. CT must

be paired with physical exam for optimal results. In a series of multicenter reviews performed by the Western Trauma Association, CT had become the most commonly performed diagnostic adjunct for stable patients with abdominal GSWs but the imaging modality was not directly compared with serial clinical examinations. The group's work clearly demonstrated a false-negative rate associated with use of CT [37]. Practically speaking, CT results will be clearly positive, clearly negative or equivocal. Therefore, if CT were solely used to exclude injuries and discharge all patients without observation, 68.8% of the injuries would have been missed, resulting in patients with equivocal imaging being sent home inappropriately. In this setting, clinical observation remains mandatory for successful SNOM [25].

At our institution, once the CT has been performed, the patients may then be divided into four groups. (1) Patients with no peritoneal violation on CT scan. In this population, it is exceedingly rare that operative intervention will be required and they may be considered for discharge home. (2) Patients with peritoneal violation but no obvious intra-abdominal injury on CT scan. These patients serve as the ideal patient population for SNOM with serial abdominal examinations, laboratory value and vital sign monitoring, and clinical observation. (3) Patients with peritoneal violation and evidence of vascular or hollow viscus injury on CT scan. In this group, laparotomy is mandatory. (4) Patients with peritoneal violation and solid organ injury. In the absence of hollow viscus injury, solid organ injury alone does not mandate laparotomy and these patients may also be trialed with SNOM [38, 39]. For SNOM candidates like those described in groups two and four, clinical observation becomes the next essential step. The observation period is the most time-consuming aspect of SNOM and one of the primary reasons it may not be feasible in all practice settings. During this time, serial surveillance should be performed by a consistent team, ideally by the same provider, who can carefully examine the patient for changes in abdominal pain, collateral markers of occult injury such as tachycardia or fever, and laboratory abnormalities such as an increasing white blood cell count. It is expected that a certain percentage of patients initially undergoing a trial of SNOM will progress to requiring operative intervention based on changes in clinical examination. Therefore, SNOM hinges on the ability to perform frequent, consistent physical examinations. Patients should receive no narcotics or antibiotics and undergo serial hemodynamic and laboratory testing including white blood cell count, lactate, and hemoglobin levels. Strict adherence to a protocol is necessary to ensure early identification of patients who fail non-operative management and require operative intervention.

The duration of observation should meet a minimum standard, which is also subject to much debate. After abdominal GSWs, a retrospective review of 270 patients found that all injuries requiring laparotomy were apparent within 24 h of observation [24, 40]. Further, multiple series have shown that almost all failures of SNOM will occur within the first 12 h to 24 h [1, 38, 41, 42]. We, therefore, recommend at least 24 h of initial close observation for optimal outcomes. Another useful advantage to a 24-h observation period comes in the setting of injuries that are notoriously difficult to diagnose with CT. Penetrating left thoraco-abdominal injuries, for example, those bounded by the nipple, scapular tip, and costal margin,

present unique challenges in diagnosis due to the risk of occult diaphragmatic injury. These injuries are often asymptomatic in the early post injury setting and tend to heal poorly. If no obvious injuries are present on CT and no peritonitis develops during the observation period to suggest the presence of a hollow viscous injury, the patient can be offered diagnostic laparoscopy to specifically evaluate the diaphragm on the left side. As hollow viscous injury has been ruled out with serial exams and 24-h observation, full exploration is unnecessary. Because the incidence of diaphragmatic injury after penetrating thoraco-abdominal trauma is 17% to 40%, it is our recommendation that all trajectories suspicious for left sided diaphragm injury be further evaluated with diagnostic laparoscopy prior to discharge [43].

We do acknowledge that most studies do not include specific details of their observation process and that our procedures may not be feasible in all settings. We recognize that with the increasing frequency of shift work and many obligations of the in-house trauma surgeon that there is a real chance that subtle changes in the physical examination could be missed. Recognizing that performing serial exams is labor intensive, we advocate for additional testing of this concept in smaller centers to ensure resources are adequate to support the 24-h observation period to the same degree of safety seen in larger centers. However, we find little rationale in the argument that lack of available experienced manpower is a reason to avoid SNOM. In agreement with Fikry et al., in a review of the safety of SNOM in a low volume trauma center, assessment of abdominal pain, hemodynamic stability, and CT findings is truly a skill that should be familiar to every surgeon [44]. Further, in a retrospective review of a prospectively maintained registry in a developing country, Laing et al. demonstrated significant reduction in non-therapeutic laparotomies and improved success with SNOM after implementing strict protocols for the procedure. By making edits from previous audits, CT was deemed essential for patients with abdominal GSWs undergoing a trial of SNOM and physical exams were performed at 4-h intervals for a 24-h period. This protocol resulted in a 99% success rate for those selected for SNOM [45]. Important to note, the group described use of trainees to perform serial physical exams thereby affirming this process does not necessarily need to be overly burdensome on the in-house trauma surgeon. Additionally, this study reinforces the concept that it is not the size or location of the trauma center, nor volume of penetrating trauma cases that translates into a safe and successful SNOM practice, but rather it is dependent upon organization and protocols that can be universally adopted.

Evidence Validating Safety and Efficacy of SNOM

In pooling data from several single institution prospective studies on SNOM for abdominal GSWs, 90% of the evaluable cohort with benign abdominal exams did not have an injury requiring surgical intervention [4, 7, 41, 42]. In a large, multicenter retrospective review, morbidity rates (8.5% vs. 34.7%; $p < 0.001$), mortality rates (0.5% vs. 5.2%; p 1/4 0.002), median ICU length of stay (0 vs. 1 day; $p < 0.001$), and median hospital stay (2 vs. 8 days; $p < 0.001$) favored the SNOM group over those who underwent immediate laparotomy [41]. In this same study,

non-therapeutic laparotomy occurred in 14.7% of patients undergoing immediate exploration and 17.3% of them developed postoperative complications. Had the centers been compliant with the EAST guidelines, 33.7% of the patients with non-therapeutic laparotomies would have qualified for SNOM in that they were hemodynamically stable, clinically evaluable, and without peritonitis. From a trauma resource utilization viewpoint, negative laparotomy is associated with an increase in unnecessary operative costs and hospital length of stay [5, 6, 14]. The introduction of SNOM for abdominal GSWs has been shown to result in a tangible cost savings [7]. Based on our experience and thorough review of the existing evidence, we consider this practice to be both safe and efficacious.

A final point to consider is whether the safety of SNOM established above is generalizable to all trauma centers. Opponents argue that routine laparotomy is likely the preferred option in inexperienced hands. However, previous studies have demonstrated that SNOM is safe, irrespective of the trauma volume, because the infrastructure and the continuity of care in a well-organized trauma center can overcome the limitations of case shortage [41, 46]. This finding was also highlighted in the work of Laing, as previously mentioned.

Recommendation Based on the Data

On the basis of the evidence reviewed and our personal experience, we recommend that any evaluable patient presenting with a GSW to the abdomen in the absence of peritonitis, hemodynamic instability, or evisceration be considered for SNOM. All patients meeting criteria should undergo CT scan and serial physical exams over a 24-h period as essential components of this process.

Patients with a penetrating injury trajectory involving the left thoraco-abdominal region should undergo a delayed diagnostic laparoscopy on the same admission to rule out diaphragmatic injury. This recommendation is consistent with the Western Trauma Association's algorithm for penetrating abdominal injuries. Patients undergoing SNOM should be observed for at least 24 h following CT scan and should undergo serial abdominal and laboratory value examinations, as well as vital sign monitoring while remaining NPO. An experienced surgeon or surgical resident should perform the physical exam during the clinical observation period. Institutional protocols outlining these steps have been shown to increase acceptance and successful outcomes for SNOM patients irrespective of the size, composition, and volume of penetrating trauma of the institution itself.

Summary of Recommendations

- SNOM of abdominal GSWs is an acceptable management strategy (Evidence quality moderate; strong recommendation).
- All patients with hemodynamic instability, diffuse peritonitis, or who are unevaluable should proceed directly to the OR for emergent exploration (Evidence quality high; strong recommendation).

- For all other patients with abdominal GSWs, CT scan is the critical next step (Evidence quality moderate; moderate recommendation).
- CT should be used to identify those who need an immediate operation, those who qualify for SNOM, and those who are safe to be discharged home without observation (Evidence quality moderate; moderate recommendation).
- During the observation period, if the patient develops evidence of a missed hollow viscous injury, then laparotomy should be performed (Evidence quality moderate; strong recommendation).
- For patients with a GSW undergoing SNOM, when the diaphragm is at risk of injury, evaluation by diagnostic laparoscopy is needed prior to discharge (Evidence quality moderate; moderate recommendation).
- Despite high-quality evidence demonstrating the safety of SNOM, the process is dependent upon a 24-h observation period in which an experienced surgeon or surgical trainee performs serial physical exams. We recommend against SNOM in favor of obligate exploration if the provider does not have the resources to support this process in its entirety (Evidence quality low; weak recommendation).

A Personal View of the Data

Data looking at SNOM for abdominal GSWs has evolved over the last two decades. For stable, evaluable patients without peritonitis, we now know that it is a safe practice. Keeping this process safe is contingent upon two critical steps. First, obtaining a CT scan. High-quality images defining the bullet trajectory allow for identification of those patients best suited for SNOM. Secondly, the institution not only must have a monitored observation unit to house the selected patients for 24 h, but also must have an experienced surgeon or surgical trainee available to perform serial physical exams in order to quickly recognize those that will require operative intervention. While we acknowledge that this may not be possible at all centers, where feasible, it will result in direct patient benefit. At our center, all patients are evaluated for SNOM. We believe it to be safe and thus the optimal choice in select patients with abdominal GSWs.

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What Is the Optimal Management of Traumatic Duodenal Injury?

21

Jonathan Kent and Peter Bendix

Introduction

Diagnostic and management challenges of injuries to the most distal section of the foregut have been discussed in the literature for over a century. Herczel was the first surgeon to describe repairing a blunt duodenal injury in 1896 [1]. This was followed by Summers' 1904 description of the repair of a penetrating duodenal injury [2]. An abundant, but unfortunately scientifically thin literature has followed. The difficulty ascribed to duodenal injuries results from their association with concurrent intra-abdominal injuries, technical challenges to operative management, and their scarcity.

In 68–86.5% of traumatic duodenal injuries a coexisting intra-abdominal injury is found [3–5]. In 50–55% of cases there is an associated colonic injury [4, 6]. An additional 23–40% of patients will have a major vascular injury with lesions to the inferior vena cava most frequently described [3, 5]. Associated injuries contribute to the high overall mortality of patients with duodenal injuries (11.1–16.7%) [6–8].

Duodenal injuries are found in only 3–5% of traumatic abdominal injuries [8]. The majority of duodenal trauma is penetrating. 79–80% of duodenal injuries result from gunshot wounds to the abdomen [2, 4]. The most frequently injured aspect of the duodenum is the second, or descending portion, which is found injured in 35% of cases [9, 10]. This scarcity precludes individual surgeons from acquiring expertise and researchers from adequately powering studies evaluating the optimal management of traumatic duodenal injuries.

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Table 21.1 AAST grading scale for duodenal trauma

	Description
Grade I	Hematoma involving single portion of the duodenum OR Laceration that is partial thickness without perforation
Grade II	Hematoma involving more than one portion of the duodenum OR Laceration that disrupts <50% of the circumference
Grade III	Laceration that disrupts 50–75% of the circumference of D2 OR laceration that disrupts 50–100% of the circumference of D1, 3–4
Grade IV	Laceration that disrupts >75% of D2 OR involves the ampulla or distal CBD
Grade V	Laceration that involves "massive" disruption of the pancreaticoduodenal complex OR Vascular injury resulting in devascularization of the duodenum

Table adapted from Moore et al. (1990) with permission from Wolters Kluwer Health, Inc. [11]

To standardize the description of duodenal injuries and facilitate their research the American Association for the Surgery of Trauma created the Organ Injury Severity Scale (AAST OIS) for duodenal injuries (Table. 21.1). The AAST OIS has allowed for surgeons to speak a common language when describing duodenal injuries; however, the optimal way to manage these different injuries is often individualized and nuanced. This chapter will attempt to synthesize the available data and expert opinion to guide the management of this complex injury pattern.

Search Strategy

A search of publications indexed on PubMed, PubMed Central, and Medline from 2010 to 2020 was used to identify published data on management of traumatic duodenal injuries. Search terms used included "duodenal trauma," "duodenum," "trauma," "pyloric exclusion," and "trauma pancreaticoduodenectomy." Studies were excluded if the primary language was not English, or if they focused predominantly on a pediatric patient population, on pancreatic injuries, or if they did not provide information regarding their studied population or other relevant clinical information. Additional publications were identified through a snowball methodology from the initially identified publications.

The initial query identified 1141 references. Following analysis of abstracts and exclusion of non-English articles, articles focusing on injuries from ERCP, and articles focused on a pediatric population, 47 articles were identified. This was narrowed to 34 articles with sufficient scope for in-depth review (Table 21.2).

Results

Imaging

In the hemodynamically stable patient, a CT scan is the gold standard for imaging identifying duodenal injuries. CT imaging has only a 70% sensitivity for diagnosing

Table 21.2 PICO review process for duodenal trauma

Population	Adult patients with duodenal trauma
Intervention	Primary repair
Comparison	Non-operative management, Berne procedure, triple tube decompression, pyloric exclusion, Pancreaticoduodenectomy
Outcomes	Mortality, intra-abdominal sepsis, leak rate, hospital length of stay, ICU length of stay

blunt duodenal injury at the time of initial presentation; however, it remains an important adjunct to the evaluation of the traumatic patient [12]. CT imaging that demonstrates extraluminal contrast in the area of the duodenum warrants emergent exploration. This finding is seldom encountered as intraluminal contrast is not frequently administered in the acute trauma evaluation. Twenty-one percent of patients with the findings of peri-duodenal hematoma and/or peri-duodenal fluid collections who have exploratory laparotomies require operative intervention on their duodenal injuries [13]. Patients with these soft findings—peri-duodenal hematoma and peri-duodenal fluid collection—on imaging should be evaluated in the context of the individual patient to determine if operative intervention is indicated.

Duodenal Hematoma

Morbidity from AAST-OIS Grade I or Grade II duodenal hematomas can result from gastric outlet obstruction. These may be found in blunt abdominal trauma patients on CT imaging. In the absence of concurrent injuries in a hemodynamically stable patient, these hematomas may be managed non-operatively. Non-operative management may be guided by nasogastric tube decompression and serial abdominal exams. If the patient remains NPO 7 days after presentation, parenteral nutrition should be considered. This non-operative management will fail in 5–10% of patients, however, is not associated with any differences in length of stay [5, 12, 13].

If gastric outlet obstruction persists for greater than 14 days, procedural intervention can be considered. These hematomas can be resolved via drainage by interventional radiology, through laparoscopic drainage, or drainage with primary repair following laparotomy [5, 13–16]. CT guided catheters placed in interventional radiology have been described in cases of pediatric trauma [15]. Laparoscopic drainage may be conducted with a needle that is inserted under direct visualization into the hematoma to allow for drainage.

Historical Procedures

Initially, it was believed that duodenal injuries required extensive repairs due to the high acidity and volume of effluent passing through the duodenum. Complex techniques such as Berne's diverticulization of the duodenum (antrectomy with vagotomy,

oversewing of duodenal stump and then performing a gastrojejunostomy) and the Triple Tube Decompression technique described by Stone and Fabian (repair with a nasogastric tube, retrograde jejunostomy for decompression, and anterograde jejunostomy for feeding) were described as surgeons attempted to protect their repairs [14, 17]. These techniques were believed to be successful and necessary. The triple tube decompression technique had excellent single-center outcomes. However, these successes have not been able to be replicated at other institutions. While these techniques are still used in some institutions, the advent of proton pump inhibitors assuaged concerns of exposing duodenal repairs to the acidity of gastric fluids [17–19].

Pyloric Exclusion

First described by Lewisohn in 1918 the pyloric exclusion is a popular, simple technique that is used to protect a duodenal repair in 19.2% of operative interventions for duodenal trauma [8, 20]. The gastric pylorus is either stapled across, or a gastrotomy is made and an absorbable purse-string is placed to occlude the lumen of the pylorus. This is commonly followed by a Billroth-2 reconstruction in which a proximal loop of jejunum is apposed in an antecolic position, identical incisions are made on the jejunum and approximated stomach and then closed with a running layer of full thickness absorbable suture and covered with an anterior serosal layer of interrupted silk sutures [21]. Endoscopic studies have demonstrated that within 3 weeks the pylorus will have opened [22]. While theoretically sound, patients who have a pyloric exclusion have no survival benefit, tend more likely to have postoperative complications, and have longer hospital lengths of stay (22.2–32.2 days, $p = 0.003$) [20, 22].

Primary Repair

Given the lack of reproducible improved efficacy of complex repairs, and the unclear benefit of pyloric exclusion, current practice suggests a primary suture repair of the duodenum. Primary suture repair of a duodenal injury is the most utilized technique in the management of duodenal trauma. Primary repair was performed in 78.5% of all repairs in the U.S. between 2002 and 2014, and subset analysis shows that it is becoming more prevalent over time [8]. Accruing data on primary repair demonstrates no difference in mortality, duodenal leak rate, and intra-abdominal sepsis rate versus more complex techniques [5, 14, 23–25]. Interestingly the only difference between primary repair and a reconstruction including a gastrojejunostomy is shorter length of stay for patients who receive a primary repair [24]. This difference in LOS without a change in mortality or morbidity persists even when evaluating only AAST OIS grade IV/V injuries [24].

Drain Placement

A recently repaired duodenal injury may have a drain placed alongside the repair. This recommendation runs against the grain of Schroeppel et al.'s observation that patients who develop a duodenal leak are more likely to have an extraluminal closed suction drain in place following their repair (90 vs. 45%; $p = 0.008$) [10]. Despite its statistical significance, this data is observational and does not adequately consider the contexts in which surgeons would choose whether a drain is indicated (concurrent liver, gastric, pancreatic, or renal injuries).

Pancreaticoduodenectomy

Unless the injury is so massive as to make a less complex repair technically impossible, a pancreaticoduodenectomy (Whipple procedure) in the acute trauma patient should be avoided [5, 14]. Complete disruption of the pancreaticoduodenal complex requires this resection and reconstruction, but it should be avoided when possible. There has been no demonstrated benefit in terms of mortality, ICU days, and hospital length of stay for patients who underwent pancreaticoduodenectomy relative to a less complex repair [26]. Patients who undergo a pancreaticoduodenectomy for traumatic injuries have a reported 13–33% mortality rate [3, 27–30]. When no other alternative than a pancreaticoduodenectomy exists, the operating surgeon should strongly consider performing the procedure in stages and, in consideration of the surgeon's comfort level, with the assistance of a hepatobiliary specialist.

A single-stage pancreaticoduodenectomy for traumatic injuries takes an additional 4 h to complete (460 min compared to 243) compared to a damage control surgery [28]. Patients who receive pancreaticoduodenectomy at time of index operation are also more likely to develop an enterocutaneous fistula (67 vs. 8%; $p = 0.04$) and intra-abdominal sepsis (100 vs. 17%) than patients who have damage control surgery prior to a staged pancreaticoduodenectomy [28]. The centers that have the best-reported outcomes with pancreaticoduodenectomies for traumatic etiologies emphasize their highly selective approach to the procedure and their preference to perform the procedure in multiple stages [28, 29].

Enteric Feeding

Patients with severe duodenal injuries can quickly become malnourished. If patients with AAST OIS grade I or II injuries remain NPO 7 days after presentation, parenteral nutrition should be considered. Patients with severe (grade IV–V) duodenal injuries will require TPN in 37–75% of cases [5]. This persists regardless of the placement of a jejunostomy feeding tube at time of operation, as 75% of patients

who undergo a triple tube decompression procedure will demonstrate jejunal tube feeding intolerance when fed within 14 days of their operation [31].

Imaging Surveillance

Follow-up imaging to evaluate a duodenal repair should not be scheduled but should be guided by a patient's clinical symptoms [5]. If a patient develops symptoms concerning for an ileus, obstruction, or enteric leak a CT scan with PO and IV contrast is indicated for further evaluation.

Recommendations Based Upon the Data

1. Hemodynamically stable patients with AAST Grade I and II duodenal injuries should be managed non-operatively (evidence quality moderate; moderate recommendation).
2. Whenever technically able Grade III–V duodenal injuries should be managed with primary repair.
3. Pyloric exclusion increases hospital length of stay and should be avoided (evidence quality moderate, moderate recommendation).
4. Pancreaticoduodenectomy should only be performed when a primary repair of a duodenal injury is technically impossible to achieve (evidence quality low; moderate recommendation).

A Personal View

Despite the scarcity of traumatic duodenal injuries, we continue to accrue data that guide their optimal management. We have learned that blunt trauma patients with low grade (I and II) injuries can be mostly managed non-operatively with supportive care. Laparotomy can often be avoided in the blunt trauma patient, and multiple non-operative or less invasive techniques are present to ameliorate persistent duodenal hematomas. In higher grade or penetrating trauma mechanisms, we have found that despite the theoretical appeal of complex operations, primary repair of these injuries remains equally if not more effective at preventing further morbidity for the patient. Primary repair and/or segmental resection of distal duodenal injuries with primary anastomosis and without pyloric exclusion is safe and often preferable. In short, the simplest answer in the case of duodenal repairs is often correct.

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Timing of Ostomy Reversal in Trauma and Acute Care Surgery

22

Ryan P. Dumas and Matthew J. Martin

Introduction

The management of colon and small bowel hollow viscus injuries or emergent pathology requiring surgical intervention has evolved significantly over the past three decades, and the complications associated with delays in diagnosis of these injuries are increasingly recognized [1, 2]. Because of the high mortality and morbidity of destructive colon injuries, during World War II the Surgeon General mandated "exteriorization of the colon" or proximal diverting colostomy for all colorectal injuries [3]. In the 1990s, however, several small prospective trials reported the benefit and safety profile of resection and anastomosis or primary suture repair over routine fecal diversion [4–6]. These findings have since been supported by larger multicenter trials from the American Association for the Surgery of Trauma [7, 8], the Western Trauma Association [9], a large Cochrane review [10], and most recently reinforced by national trauma organization guidelines [11–13]. Overall, stoma creation for both blunt and penetrating injuries is low and has decreased over the past two decades supporting a trend toward primary repair [3]. Nonetheless, less experienced trauma surgeons tend to favor diversion for the management of colon injuries [14] and data suggests that colostomy remains the most common response when surgeons are given trauma scenarios [15]. There is also

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persistent and considerable confusion in the literature between risk factors for enteric/anastomotic leaks and indications for ostomy creation. For example, transfusion during an index operation is a commonly cited reason for performing a colostomy, when in fact transfusion is a risk factor for complications regardless of whether an ostomy is performed. It is critical in reading and interpreting the existing literature that surgeons have a clear understanding of specific factors that would indicate a possible benefit of a diverting proximal stoma versus risk factors that simply point to a higher rate of morbidity regardless of whether an ostomy is performed.

Despite a clear trend away from ostomy creation, stomas may be indicated in cases of severe patient comorbidities, extremes of age, clinical instability, or multiple high-risk injuries such as combined pancreatic and colon injuries. In addition to the potential immediate benefits versus harms of an ostomy, it is also important to consider the longer-term impacts and problems. These patient populations, and particularly victims of trauma, have a well-documented higher rate of being uninsured or underinsured and resulting difficulties with follow-up and navigating the healthcare system. Follow-up postoperatively for ostomy closure has been shown to be highly sporadic, with widely varying rates of subsequent ostomy reversal [16]. In the elective literature 6–32% of "temporary stomas" become permanent loop or end ileostomies, and less than 50% of colostomies are subsequently reversed. Recent data, however, suggests that reversal rates in trauma patients may be higher than previously thought. In a recent analysis of trauma patients using a statewide database, investigators found that 41% of all stomas were reversed at 6 months and 72% at 5 years [3]. Because the surgery for ostomy closure or reversal carries significant morbidity [17, 18], the existing colorectal data suggests waiting 60–90 days prior to reversal [18]. Data from the 1980s suggested that there may be increased morbidity if colostomy closure is performed within 6 weeks [19], while other more recent data suggests that the morbidity of colostomy closure may increase with passage of time with the lowest complications rate between 1 and 2 months [20]. These studies also highlight the fact that in analyzing and discussing the risk versus benefit profile of ileostomy or colostomy versus a primary repair/anastomosis, the morbidity and cost of the subsequent ostomy reversal surgery must also be factored in. This is a well-known limitation of the majority of literature comparing ostomy versus primary repair or anastomosis, and falsely lowers the complication and risk profile in the ostomy cohort. In fact, we are unaware of a single existing study comparing ostomy versus primary repair/anastomosis in trauma or emergency general surgery that shows a benefit of ostomy placement when this data is included in the analysis.

Given animal studies that suggest colon wounds are healed after 7 days and contrasted radiographic studies in humans demonstrating wound healing as early as a week from injury [21], surgeons have sought to decrease the time interval between the index operation and stoma creation to a subsequent reversal surgery. Some studies have even examined the same admission ostomy reversal in select patients, although this represents a minority of published experiences. This chapter will review the evolution of evidence supporting early stomal closure in two distinct

patient populations, trauma, and general surgery (emergency and colorectal surgery). We will additionally review the available evidence for both temporary ileostomy and colostomy early reversal. Current data suggests that less than 15% of stomas created are reversed during the same hospital admission [3].

Search Strategy

Our search strategy utilized PUBMED using the keywords, stoma, ostomy, colostomy, ileostomy, early, late, closure, trauma, timing, same admission, and reversal. The references of selected papers were also reviewed to identify additional papers that may have been missed by the primary search. We focused on four patient populations and four PICO questions (see Table 22.1). For purposes of recommendations based on modern practices and literature we limited our search to include only manuscripts from 1990 to 2020.

Results

Early Versus Delayed Stomal Closure for *Trauma Patients* Requiring Fecal Diversion with an *Ileostomy*

There is insufficient evidence to support early ileostomy reversal in the setting of colorectal trauma. While Velmahos et al. included diverting loop ileostomies for ascending colon trauma in their randomized investigation in trauma patients, due to the small sample size of the study, none of these patients were randomized to the early reversal intervention group [22]. Early reversal of diverting loop ileostomies matured in order to "protect" a colorectal anastomosis or a primary repair in the setting of trauma has not been studied. However, there is ample evidence from both

Table 22.1 PICO questions for early versus late ostomy reversal

P (patients)	I (intervention)	C (comparator)	O (outcomes)
Trauma patients requiring fecal diversion following small bowel or colorectal trauma with ileostomy	Reversing ostomy early (<30 days)	Reversing ostomy late (>8 weeks)	Morbidity
Trauma patients requiring fecal diversion following small bowel or colorectal trauma with colostomy	Reversing ostomy early (<30 days)	Reversing ostomy late (>8 weeks)	Morbidity
General surgery patients (general, emergency, colorectal) requiring fecal diversion with ileostomy	Reversing ostomy early (<30 days)	Reversing ostomy late (>8 weeks)	Morbidity
General surgery patients (general, emergency, colorectal) requiring fecal diversion with colostomy	Reversing ostomy early (<30 days)	Reversing ostomy late (>8 weeks)	Morbidity

elective and emergent colorectal procedures that early ileostomy reversal is a feasible and safe option, and little reason to suspect that there would be significant differences between the healing and leak rates seen with emergent colorectal resections versus emergent trauma resections. Further study in the trauma population is necessary to confirm this, particularly as resection with anastomosis and proximal diverting loop ileostomy is becoming a more widely appreciated option for higher-risk anastomoses.

Early Versus Delayed Stomal Closure for *Trauma Patients* Requiring Fecal Diversion with a *Colostomy*

Studies supporting early stomal closure in patients suffering from colorectal trauma are mainly limited to proximal diverting or end colostomies. While the literature dates back three decades, the quality and quantity of the literature remain low and recently updated practice management guidelines from the Eastern Association for the Surgery of Trauma for both extra- and intra-peritoneal colorectal injuries do not address the timing of colostomy reversal [11, 13]. The Western Trauma Association's critical decisions algorithm, suggests an early reversal is feasible based on two studies conducted in the mid-1990s [12]. The first, from Renz et al., introduced the concept of same admission colostomy closure (SACC) for trauma patients and has laid the groundwork for subsequent similar trials. Sixteen patients in this report underwent SACC following diversion for either blunt or penetrating injury mechanisms at a median of 12 days after the index operation. Three patients had postoperative complications, none related to the traumatic colorectal wound or anastomotic leak [16].

Two years later in 1995, *Velmahos* et al. randomized 38 patients to early versus late colostomy closure following colorectal trauma. Eighteen patients underwent early closure. The investigator found no difference in morbidity or mortality between the two groups [22]. Patients all underwent contrast enema in the second postoperative week. However, the authors did identify multiple benefits associated with earlier ostomy reversal including shorter operative times, less blood loss, and a decreased length of stay. They also demonstrated significantly greater technical difficulty with reversing end colostomies versus loop colostomies. Some of these findings have since been challenged by larger studies in elective patient populations that demonstrated generally equivalent complication rates [23, 24]. However, they did similarly find several benefits including shorter hospital stay, lower costs, and improved quality of life scores in the groups randomized to early ostomy reversal [23, 24].

A decade later in 2005, Khalid et al. performed a larger randomized trial of 60 patients undergoing SACC, with the majority of patients (80%) suffering from traumatic colon injuries. The authors concluded that early closure group ($n = 30$) had a shorter length of stay, reduced cost, improved quality of life, and early return to work [25]. Most recently, Nelson et al. reported the benefits of early stomal closure

in a mixed patient population but their analysis does not include a breakdown of the percentage of patient that underwent diversion for trauma [24]. Taken together, these series indicate that early or same admission colostomy reversal in select patient populations can be performed safely and with equivalent or better complication and quality of life profiles.

Early Closure Versus Delayed Closure for *General Surgery* (*Emergency and Colorectal*) Patients Requiring Fecal Diversion with *Ileostomy*

The most robust evidence supporting early stomal closure is in elective colorectal surgery for patients undergoing diversions following low colorectal anastomoses with a temporary ileostomy. While retrospective data supporting early closure (within 14 days) [26, 27] and small randomized pilots trials have been published [28–31], the best evidence is from three larger, randomized trials. Most recently, Danielsen et al. reported the results of the EASY Trial a multicenter European trial in 2017 [32]. Fifty-five patients who were diverted following rectal cancer operations underwent early ileostomy closure between 8 and 13 days after the index operation. All patients underwent preoperative radiographic evaluation to confirm the absence of an anastomotic leak or stricture prior to reversal. The investigators found that patients undergoing early reversal had a significantly lower rate of complications at 3, 6, and 12 months (OR 1.2 vs. 2.9, $p < 0.05$).

In a 2010 study, Khan et al. compared two large groups with over 150 patients in each cohort [33]. These investigators compared early closure (within 4 weeks) to late closure (after 8 weeks). The authors concluded that the total hospital length of stay was shorter, but the incidence of surgical site infection was higher in the early group. Importantly, the absolute rates of anastomotic leak and wound dehiscence were lower in the early closure group, although the difference did not reach statistical significance. While their conclusions are similar to other studies and support the safety and efficacy of early ostomy reversal, it is important to note that their definition of "early" (4 weeks after index operation) differs from other studies.

Finally, Aveles et al. reported the largest randomized trial to date in 2008 in patients undergoing early ileostomy reversal after proctectomy. These investigators similarly found that patients undergoing early closure ($n = 90$) had an equivalent overall rate of complications, fewer obstructive and medical complications, but an increased incidence of surgical sites infections [23]. Interestingly, despite the increased wound infection rate in the early closure group, the hospital length of stay was shorter after early closure. In addition, and unlike prior studies, this study did not find that delayed closure was associated with increased operative times. In summary, this literature appears to strongly support the safety and efficacy of early ileostomy reversal in a variety of general surgery populations, with most outcomes being equivalent or superior to delayed stoma reversal.

Early Closure Versus Delayed Closure for *General Surgery* (*Emergency and Colorectal*) Patients Requiring Fecal Diversion with *Colostomy*

There is insufficient evidence to support early closure of colostomies performed in the setting of emergency surgery and colorectal surgery. In 2018, Nelson et al. reported a randomized controlled trial that included >80% emergency general surgery patients and a mix of diverting stomas that were closed at a range of 14–26 days in the early group. However, it is critical to note that of the 50 patients in the early cohort, only 18 patients had colostomies [24]. The investigators found no difference in postoperative complications, but did demonstrate decreased costs and an improved quality of life with early colostomy reversal. Similar to other investigations, these authors also reported higher surgical wound infections in the early group, but this did not seem to adversely impact the length of stay, costs/charges, or patient quality of life. Some small retrospective series with mixed patient populations have also confirmed similar outcomes [34].

A more recent large database analysis examined 1660 patients who underwent an emergent Hartmann's procedure (sigmoid resection and end colostomy) for diverticulitis [35]. They found that earlier ostomy reversal (defined as 45–110 days from the index surgery) was associated with a shorter length of stay and 90-day readmission rate, and no increased risk of anastomotic leak or other complications. Of interest, they demonstrated that less than one-third of patients underwent colostomy reversal within 1 year and that socioeconomic factors influenced this metric.

Systematic Reviews for Early Closure Versus Delayed Closure

Several meta-analyses have been published investigating the timing of stomal closure [36–40], taken together and taking into account the heterogeneity of the data, these data suggest and favor early stomal closure with comparable and improved outcomes compared to delayed closure with the exception of wound complications. However, it is important to note that four of the five analyses focused on diverting loop ileostomies, and they included a wide mixture of patient populations including non-emergent elective colorectal resections. They also used a wide and variable definition of "early" ostomy reversal ranging from as early as 7 days to as late as several months after the index operation.

Examining the Need for Diverting or "Protective" Ostomies

This chapter focuses on the question of early versus late ostomy reversal and starts with the presumption that a diverting or protective ostomy has been created. The cumulative data appear to indicate that early ostomy reversal in the properly selected patient is safe and associated with improved outcomes versus delayed closure.

However, it is also critically important to consider the additional question of whether creation of the ostomy is associated with better or worse outcomes than would be achieved with performing a primary repair or anastomosis and foregoing any ostomy creation. Although ostomy creation has historically been the norm for destructive colorectal injuries or emergent colon resections, the past several decades have demonstrated accumulating body of evidence supporting the safety and efficacy of primary anastomosis without an ostomy for most injuries or disease pathologies [6, 7, 9, 10, 12, 13]. In addition to further study regarding the practice of early or even same admission ostomy reversal, there must be continued analysis of the outcomes associated with primary repair/anastomosis as a definitive treatment even in the emergent setting, and a better characterization of which risk factors can reliably identify the small subgroup of patients who would be benefited by creation of an ileostomy or colostomy.

Recommendations Based on Data

1. Recovering trauma patients with temporary diverting loop colostomies can be considered for early, same admission colostomy closure after radiological confirmation of wound healing and no anatomic contraindication to reversal (Evidence quality moderate; moderate recommendation).
2. Earlier ostomy reversal (defined as 45–110 days from the index surgery) is associated with a shorter length of stay and 90-day readmission rate without an increased risk of anastomotic leak or other complications (Evidence quality moderate; moderate recommendation).

Personal View of Data

As academic and clinical surgeons, it is always good to identify and question our inherent biases or "surgical truths" that have been handed down based on anecdote rather than evidence. The management of colorectal trauma and emergency surgery for colorectal diseases is an area that has been particularly dominated by dogmatic approaches and practices, but where there also has been steady progress forward based on both accumulating experience and high-quality data analysis. We have moved from a position of mandatory ostomy or "wound exteriorization" for all traumatic colon injuries to the understanding that the majority can be treated with primary repair or resection and primary anastomosis without ostomy creation. Similarly, and thankfully, we are also slowly moving away from the Hartmann's procedure in favor of resection and anastomosis or anastomosis with proximal diverting loop ileostomy for perforated or complicated diverticulitis. It is our opinion that the Hartmann's procedure should be relegated to the least frequently utilized operation, reserved only for the dire straits of severe physiologic illness, extremes of age and comorbidities, or complex anatomic abnormalities that

preclude an anastomosis. In the authors' current practice the overall usage of a diverting colostomy has decreased significantly, the use of primary anastomosis continues to increase even for destructive colon injuries or Hinchey grade III/IV diverticulitis, and if a diverting ostomy is felt to be necessary then is most commonly a temporary loop ileostomy.

For the patient who did receive or require (which are two different things) an ostomy, we are then faced with the complex questions of whether to reverse it, when to reverse it, and how to safely make these decisions. Table 22.2 outlines some of the complex factors and decisions that we must make when dealing with colorectal injuries or emergency surgery, including the decision for attempting an early versus a standard (or late) reversal. Arguably the most important factors in this decision are patient stability, associated injuries or active medical problems, and the type/location of repair or anastomosis that is being protected. In terms of the type of ostomy, the most important factor in this consideration is whether a loop colostomy/ileostomy was created versus an end stoma. The former is much more amenable to early or even "same admission" reversal as they typically only require a local mobilization, anastomosis, and return to the abdominal cavity and not a repeat laparotomy or abdominal exploration. We believe that the majority of data strongly supports the safety and efficacy of early reversal (within 1–4 weeks) of loop ostomies providing that there are no other risk factors as outlined above and in Table 22.2. Although the data in the trauma population on this topic is much less robust compared to emergency and elective colorectal surgery, there is little reason to suspect that the outcomes would be markedly different provided that appropriate patient selection and preoperative evaluation protocols are utilized. For end colostomy or ileostomy, the risk:benefit calculus is significantly different as these will typically require a repeat laparotomy (although laparoscopy is being increasingly utilized) to take down the stoma and perform the anastomosis to re-establish intestinal continuity. These reversal procedures can be particularly difficult if it requires dissection back into an area that had significant inflammation and/or infection, such as reversing a Hartmann's procedure done for Hinchey III or IV diverticulitis. In these cases, we believe it is wiser to not attempt early or same admission stoma reversal, and to delay this procedure until at least 6–8 weeks later. However, for the majority of patients, we do not feel that additional and usually arbitrary time delays (3–6 months for example) offer any benefit unless the patient has additional active issues or contraindications that need time for treatment and resolution. Prior to ostomy reversal, and of particular importance when attempting any early reversal, is the preoperative evaluation of the existing anatomy and status of any repairs or anastomoses. This is usually best accomplished by a contrast study to evaluate for any leak or stricture, although endoscopy can be utilized in select scenarios. Another critical factor, and one that can result in devastating outcomes if overlooked, is assessing the anorectal complex, sphincter tone, and voluntary function to ensure that the patient will not have major fecal incontinence problems after restoring intestinal continuity.

Table 22.2 Key intraoperative and early postoperative management issues and decisions in colorectal trauma

Key decision	Factors to consider	Technical issues/pearls
Primary repair or resection?	Size of injury Shape of injury (linear, round/stellate) Single or multiple Tissue quality Mesentery status (rents, hematomas, devascularized)	Debride injured or burned tissue Connect close injuries rather than leaving "bridges" Evacuate large mesenteric hematomas Close mesenteric tears Resect segment with "bucket-handle" mesenteric defect
Damage control?	Patient stability Transfusion requirement Acid/base getting better or worse? Multiple injuries? Another reason for a "second-look" (i.e., bowel viability)	Make a decision early in case Proceed if patient improving, terminate if getting worse Vacuum-assisted temporary closure works best Usually no need for other drains
Anastomosis or ostomy?	Patient baseline status (age, comorbidities, meds) Physiologic status Quality of the tissues Other injuries and proximity to anastomosis Body habitus, ability to properly site an ostomy	Consider difficulty and risk of ostomy takedown Be wary of anastomosis with an associated pancreatic injury! Obesity increases difficulty and complications with ostomy Consider ostomy complication profile in risk:Benefit analysis
Anastomosis: Hand-sewn or stapled?	Operative time Other injuries to address Personal experience and comfort Tissue quality, edema Anatomic area and bowel alignment, available equipment	No difference in leak or complication rates in most series Hand-sewn potentially more secure with suboptimal tissue quality, bowel wall edema Laparoscopic staplers great for pelvis, hard-to-reach areas or sharp angles
Ostomy: Loop, end, other?	High-risk anastomosis that needs protection? Need access to distal bowel segment? Body habitus Mesentery—Shortened, edematous	Loop may reach skin easier with obesity or short mesentery May not get complete fecal diversion with a loop Remember the "end-loop" option (see text) Use an ostomy bar if any tension or obese patient
Leave a drain?	No indication for routine drainage of bowel anastomoses Widely drain any other adjacent injuries (pancreas, bladder, etc.) Other reasons: Associated abscess cavity, control ascites	Avoid direct contact of drain with anastomosis Larger sump drains usually not beneficial Make exit site remote from incision and any ostomy

(continued)

Table 22.2 (continued)

Key decision	Factors to consider	Technical issues/pearls
Early ostomy reversal?	Type and location of anastomoses or primary repairs Presence/severity of associated injuries vs. isolated injury Normalization of patient physiology Age, comorbidities, any impaired healing Current substance use/abuse, nutritional status Anorectal complex integrity, function, continence	Early or same admit loop ostomy reversal feasible in select low-risk patients based on these listed factors Preop contrast study demonstrating no leak, stricture, other abnormality End ostomy requiring laparotomy for reversal usually better to delay at least 2–3 months

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Part VII

Thoracic Trauma

Resuscitative Thoracotomy

23

Amy V. Gore, Clay Cothren Burlew, and Ernest E. Moore

Introduction

While thoracotomy as a resuscitative measure has been described dating back to the late 1800s, it was most commonly used as a means to provide open cardiac massage following medical causes of cardiovascular collapse [1, 2]. In the 1960s, Kouwenhoven and Zoll [3, 4] published on closed chest compressions and electrical defibrillation and essentially eliminated its role in medical cardiac arrest. Beall et al. in 1966 reestablished the utility of immediate thoracotomy in trauma, specifically for the salvage of patients sustaining life-threatening chest wounds [5]. In the decades since, outcomes of EDT have been analyzed extensively, allowing for the identification of clearly defined indications that attempt to maximize survival while limiting cost and risk to providers [1, 6–12].

For the purposes of this chapter, emergency department thoracotomy (EDT) refers to thoracotomy performed on patients in extremis on arrival to the ED at the time of first contact. It does not include resuscitative thoracotomies performed in a prehospital, operating room (OR), or intensive care unit (ICU) setting. In addition, "signs of life" (SOL) are considered to be the presence of detectable blood pressure, pupillary response, spontaneous breathing or motor response, or cardiac electrical activity [1].

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The physiologic rationale behind EDT are myriad. Access through the left chest allows for quick identification and release of pericardial tamponade. Combined with venting of the right chest and extension to a clamshell incision if right chest hemorrhage is identified, EDT allows for control of cardiac or intrathoracic hemorrhage, evacuation of bronchovenous air embolism, open cardiac massage, and placement of a thoracic aortic cross clamp [13, 14].

Much of the data regarding EDT has been stratified into groups based on mechanism of injury (MOI) and presence or absence of SOL. While there is a clear role for EDT in patients who arrive with vital signs and arrest during resuscitation, controversy exists as to its use in patients requiring pre-hospital CPR.

Search Strategy

A search of English language publications was performed including the years from 2000 to 2019 to identify published data on the indications for and outcomes of EDT. The PubMed database was searched using the following terms [number of results]: “emergency department thoracotomy” [1008], “resuscitative thoracotomy” [185], and “trauma arrest thoracotomy” [214]. Results were then screened for relevance. References of relevant studies were screened for missed studies. As would be expected given the population at hand, no randomized controlled trials exist. The majority of the relevant literature is comprised of retrospective single institution case series, constituting a low quality of evidence according to the GRADE system. Given the overall low quality of evidence, studies selected for review consisted of retrospective reviews of prospectively maintained databases, multicenter retrospective reviews, and practice management guidelines from major trauma organizations in the United States.

The question at hand is which patients who present to the ED in extremis benefit from EDT in terms of hospital survival to discharge and neurologic recovery. Patients have historically been stratified into groups according to mechanism of injury and whether or not signs of life are present either in the field or in the ED. While a theoretical resuscitation-only comparator group exists, this is not borne out in the literature, as EDT is a salvage maneuver only performed in the face of near certain mortality.

Results

Summary of Available Evidence

Rhee et al. undertook a literature review of 25 years of EDT experience in 2000, identifying 4620 patients from 24 studies who underwent EDT for blunt and penetrating injury. They demonstrated an overall survival rate of 7.4% (8.8% penetrating, 1.4% blunt) [7]. Penetrating injuries were subdivided into stab wounds (SW),

with a 16.8% survival rate vs. (GSW), with a 4.3% survival. When stratifying for the presence of signs of life, those that had SOL in the hospital survived more often than those that did not (11.5 vs. 2.6%). Furthermore, 8.9% survival was reported for SOL during transport vs. 1.2% if no SOL in the field. These authors recommended EDT for patients with penetrating injury and at least one SOL in the field and patients with a blunt injury who lose SOL in the hospital or immediately before arrival. They advised against EDT in patients without SOL in the field regardless of mechanism [7]. These findings were supported by the American College of Surgeons (ACS)—Committee on Trauma (COT) in their practice management guidelines published in 2001. These PMGs were issued after the COT performed a comprehensive review of all available literature spanning from 1966 to 1999. Of the 92 references meeting selection criteria, 29 consisted of class II evidence, and 63 consisted of class III evidence. All studies were of low quality according to GRADE classification. The COT's review of 42 series dealing with a general trauma population found an overall survival rate of 7.83% (11.16% penetrating, 1.6% blunt). Of the 14 studies reporting neurologic outcome, the authors found a 5% survival rate with 15% of survivors suffering neurologic impairment. In the 46 series dealing specifically with penetrating cardiac injuries, survival rate was 31.1%. The PMGs called for performance of EDT on patients sustaining penetrating cardiac or other thoracic injuries after short transport time with witnessed or objectively measured signs of life, those sustaining exsanguinating penetrating abdominal vascular injury, and those following blunt trauma who experience a *witnessed* cardiopulmonary arrest at the trauma center [8].

Seamon et al. performed a multicenter retrospective review of consecutive EDT for penetrating injury to the heart and great vessels between the years of 2000 and 2007 [9]. This group reported an overall survival rate of 5.3%. When subdivided by injury type, patients presenting following SW were significantly more likely to survive hospital discharge than those presenting with GSW (24.2 vs. 2.8%, $p < 0.001$), with 18.2% and 2.8% of patients neurologically intact, respectively [9].

Eighteen centers in the Western Trauma Association (WTA) conducted a prospective multicenter trial from 2003 to 2009 with the objective of identifying injury patterns and physiologic profiles on ED arrival that are compatible with survival following EDT. Moore et al. reported on 56 survivors over a 6-year period [10]. Survival rate cannot be calculated as total number of EDT was not requested. Injury mechanism was most commonly SW(30), then GSW (21), followed by blunt (5). Thirty-four percent of survivors underwent prehospital CPR ranging from 1 to 15 min following penetrating injury, and 3–9 min following blunt trauma. Seven patients presented in asystole, all with pericardial tamponade. Moderate-to-severe anoxic brain injury was present in 18% of survivors at hospital discharge, however, no injury pattern was predictive of poor recovery [10].

The Practice Management Guideline Committee of the Eastern Association for the Surgery of Trauma (EAST) performed a systematic review of all studies of patients undergoing EDT with reported survival outcomes in order to provide recommendations. The review ultimately included 72 studies providing information

about 10,238 patients. There was an overall survival rate of 8.5% (10.6% penetrating, 2.3% blunt). These results were then viewed in the context of six distinct PICO questions subdividing the patient population by penetrating thoracic injury, penetrating extra-thoracic injury, and blunt injuries, both with and without signs of life on presentation. The authors report a 21.3% survival rate following EDT for patients with penetrating thoracic injury presenting with SOL and an 8.3% survival rate in those presenting without SOL. For patients with extra-thoracic penetrating injury, 15.6% of those that presented with SOL survived as compared to 2.9% of those who presented without SOL. Patients presenting pulseless after traumatic injury have uniformly worse outcomes, with 4.6% of those presenting with SOL surviving as compared to 0.7% of those presenting without SOL. This group strongly recommended EDT for pulseless patients with penetrating injury and SOL and conditionally recommended EDT for all other groups with the exception of conditionally recommending *against* EDT in pulseless patients with blunt injury and no SOL. Given poor data, this group declined to include limits for duration of prehospital CPR [11] (Table 23.1).

Slessor and Hunter looked at outcomes following blunt injury specifically, performing a review of 27 articles describing 1369 patients undergoing EDT. Of these 21 (1.5%) were recorded as having survived with good neurologic outcomes. On meta-analysis, the highest survival rates were seen in patients with vital signs or signs of life present in the ED, however, the probability of poor outcome was 99.2% (95% CI 96.4–99.7%) [12] (Table 23.2).

Table 23.1 PICO table for Emergency Department Thoracotomy

P (Population)	I (Intervention)	C (Comparator Group)	O (Outcomes)
Patients presenting to the ED in extremis – With SOL – Without SOL Mechanism – Penetrating – Blunt	EDT	Resuscitation only	Hospital survival ± Neurologic recovery

Table 23.2 Survival following EDT subcategorized by mechanism of injury

Author (year)	Overall survival	Penetrating	Blunt
Rhee (2000)	341/4620 (7.4%)	273/3173 (8.8%)	15/1047 (1.4%)
ACS-COT (2001)	551/7035 (7.8%)	500/4482 (11.2%)	35/2193 (1.6%)
Seamon (2009)	15/283 (5.3%)	15/283 (5.3%)	n/a
Seamon (2015)	871/10,238 (8.5%)	674/6390 (10.6%)	50/2172 (2.3%)
Slessor (2015)	21/1369 (1.5%)	n/a	21/1369 (1.5%)
Moore (2016)	106/1708 (6.2%)	82/905 (9.1%)	24/803 (2.9%)
DuBose (2018)	16/310 (5.1%)	13/197 (6.5%)	3/113 (2.6%)
Joseph (2018)	213/2229 (9.6%)	179/1254 (14.3%)	34/975 (3.4%)

Table 23.3 Summary recommendations

Mechanism	Signs of life?	CPR time[a] (min)	EDT recommended?
Penetrating - torso	Yes/No	<15	Yes
Penetrating - extremity	Yes/No	<5	Yes
Blunt	Yes	<10	Yes
Blunt	No	<10	Yes

[a]If CPR time unknown, perform pericardial FAST. Terminate resuscitation efforts if no cardiac motion and no pericardial fluid

The AORTA registry of the AAST is part of a prospective observational study of patients undergoing aortic occlusion in trauma that was initiated in 2013. Dubose et al. analyzed registry data to determine the effect of these PMG on practice or outcomes. From 2013 to 2016, the registry enrolled 310 patients from 16 centers undergoing EDT with aortic occlusion. 63.5% of EDT were performed following penetrating injury, most commonly GSW (82.7%). While 59% had CPR in progress on arrival, only 47.4% had documented SOL. Overall survival achieved in 5.1% (6.5% penetrating, 2.6% blunt). Patients sustaining blunt trauma without SOL underwent 14% (45/310) of EDTs with no documented survivors. Of note, the potential for bias exists in this data set as only patients that underwent EDT with subsequent cross-clamping were included in the registry, potentially excluding those successfully treated for tamponade [15] (Table 23.3).

Joseph et al. looked at 2229 patients undergoing EDT between 2010 and 2014 in the ACS Trauma Quality Improvement Program (TQIP) database. In this patient set, 56% of patients had penetrating mechanism and 71% had SOL on arrival. Overall survival rate was 9.6% (14.3% penetrating, 3.4% blunt). Patients sustaining SW survived more often than those sustaining GSW (30 vs. 10.35%, $p < 0.001$). Patients who survived were more likely to be younger ($p = 0.002$) with no patients >70 surviving, regardless of mechanism. Survivors also were more likely to present with SOL ($p < 0.001$) and were less likely to receive prehospital CPR ($p < 0.001$) [16].

In a large single-center prospective observational study, Moore et al. examined success to rescue and survival rates following EDT over the last four decades [17]. Out of 1708 patients, 419 (24.5%) had success to rescue, defined as return of spontaneous circulation and transfer to the operating room (OR). The rate of success to rescue increased over the time examined, with 22% of patients surviving to the OR in the 1970s, and up to 35% in the 2010s. This improvement in survival was most significant in blunt trauma, with 1% survival in the 1970s and 13% in the 2010s. Of those surviving to the OR, 147 (35%) survived to ICU admission and 106 (72%) survived to discharge. The rate of survival to ICU admission did not change over time. Patients who survived to discharge were more likely to have sustained injury to the thorax ($p = 0.004$), with stab wounds having the highest survival rates. As previously described, those undergoing prehospital CPR had significantly worse survival than those who did not (10 vs. 34%). The majority of survivors had no permanent neurologic deficits (68%) or mild disability (12%) [17].

In an attempt to further elucidate the contraindications to EDT, Inaba et al. investigated the ability of bedside FAST examination to discriminate between survivors

and non-survivors. In this prospective observational trial, FAST examination was performed either just before or concurrent with EDT. Ultrasound findings, including quality of window, presence of cardiac motion, and presence or absence of pericardial fluid were recorded prospectively. Two hundred twenty-three patients underwent EDT with 187 having a FAST performed. Of those, 6 (3.2%) survived to hospital discharge, with another 3 (1.6%) surviving to organ donation. The presence of cardiac motion alone for identifying survivors or donors demonstrated 100% sensitivity and 73.7% specificity. No patient in the study without either cardiac motion or pericardial fluid survived or became a donor [18].

Given the survival benefit in the adult population, the COT has recommended application of their PMGs to pediatric trauma patients despite a paucity of data on outcomes in this population [8]. Several groups have recently worked to better define the role of EDT in pediatric trauma arrest. Allen et al. performed a single institution retrospective review of their 25-year experience as well as a concurrent systematic review of all published reports of pediatric EDT over the past 40 years [19]. In their single-center review, 61 pediatric patients underwent EDT. Median age was 16 years, with males representing 90% of patients and 88% sustaining penetrating injury. Success to rescue was achieved in 23 patients (38%), however, only 2 (9%) survived to hospital discharge. A total of 252 patients were analyzed in systematic review; again the majority were male (84%) and adolescent (median age 15). Survival to rescue was achieved in 30%, however, overall survival was 6% (10.2% for penetrating injury, 1.6% in blunt trauma). When the younger pediatric population was analyzed (≤12 years), of 37 patients, 6 (16%) achieved survival to rescue, with only one surviving to discharge [19]. Moore et al. retrospectively reviewed a prospectively maintained database on all patients undergoing EDT from 1974 to 2014, including 179 pediatric patients [20]. In this pediatric cohort, median age was 16 years, 78% were male, and 56% sustained a penetrating injury; overall survival was 3.4%. When subdivided into pediatric (≤15 years) vs. adolescent (16–18 years), pediatric sustained more blunt injury (72 vs. 32%; $p < 0.001$) with a correspondingly higher rate of survival in the adolescent population (4.8 vs. 0% $p = 0.036$). Moskowitz et al. built on this work, combining a prospectively maintained retrospective database with abstracted data from all available studies over the past four decades. This study examined outcomes from 269 pediatric EDT; 121 performed for blunt trauma and 148 for penetrating. The authors report overall survival of 1.7% for EDT performed for pediatric victims of blunt trauma, with no survivors in the past 25 years, and 14% survival in EDT following penetrating trauma. No pediatric patients under the age of 15 survived following EDT for blunt trauma [21]. Flynn-O'Brien et al. further examined the pediatric blunt trauma population by analyzing multi-institutional data from the national trauma data bank [22]. This study identified 84 pediatric patients undergoing EDT. While the majority (81%) had at least one documented vital sign and/or GCS greater than 3 in the field, 44% were pulseless on arrival. None of this cohort of pediatric patients with blunt trauma arrest survived to hospital discharge. While 34 patients (40%) achieved survival to rescue, 21 (25%) died in the OR and 13 (15%) died in the ICU. These data

suggest that while EDT may have a role in penetrating trauma in the pediatric population, particularly in patients ≥15 years of age, EDT does not appear to have a role in blunt trauma in this population.

Recommendations Based on the Data

While the available data on EDT is of low-to-moderate quality, consisting largely of prospective observational studies, unmatched retrospective reviews, and case series, the alternative is near-certain death. We strongly recommend EDT for patients sustaining penetrating injury and presenting pulseless with SOL as these patients, especially following thoracic SW, have the highest overall and neurologically intact survival following EDT. We conditionally recommend EDT for pulseless patients sustaining penetrating truncal injury presenting without SOL with CPR time less than 15 min as well as for pulseless patients sustaining blunt injury with SOL and CPR time less than 10 min. Furthermore, if the timing of CPR is uncertain, we conditionally recommend pericardial FAST, with termination of resuscitative efforts if there is documented absence of cardiac motion and no pericardial effusion.

Summary of Recommendations

- We recommend a resuscitative thoracotomy for patients sustaining penetrating injury and presenting pulseless with signs of life, especially following thoracic stab wounds (evidence moderate; strong recommendation).
- We conditionally recommend a resuscitative thoracotomy for pulseless patients sustaining penetrating truncal injury presenting without signs of life and with CPR time less than 15 min (evidence moderate; moderate recommendation).
- If the timing of CPR is uncertain, we conditionally recommend pericardial FAST, with termination of resuscitative efforts if there is documented absence of cardiac motion and no pericardial effusion (evidence moderate; moderate recommendation).

Personal View of the Data

Our preferred approach to EDT utilizes the WTA algorithm published by Burlew et al. in 2012. Patients without electrical cardiac activity in the field are declared dead. Those that are in extremis, but with electrical cardiac activity, undergo resuscitative efforts and rapid transport, ideally with activation of the trauma team prior to arrival so EDT can be prepared for. Upon hospital arrival, CPR time is ascertained from prehospital providers. If CPR has been ongoing for >15 min in penetrating (>5 min if penetrating extremity or neck trauma) or > 10 min following blunt trauma, and the patient remains pulseless without signs of life, the patient is

pronounced. Additional contraindications to EDT include obvious non-survivable traumatic brain injury and presence of rigor mortis. EDT is performed if those thresholds have not been met, cardiac motion is observed, or if the patient is in profound refractory shock with SBP <60 despite massive transfusion [1, 13, 14].

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Extracorporeal Membrane Oxygenation for Patients with Traumatic Injury and Respiratory Failure

24

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Introduction

Extracorporeal membrane oxygenation (ECMO) is a form of extracorporeal life support (ECLS) in which a patient's blood is withdrawn from a central vein by a mechanical pump, directed through a membrane oxygenator comprised of hollow fibers allowing for diffusion of oxygen and carbon dioxide, and returned to a central vein or artery. ECMO can provide cardiovascular support, respiratory support, or both, based on the configuration. This technology has evolved since its first clinical application in 1972 [1] and is increasingly used for a variety of cardiac and respiratory pathologies [2–4].

The first patient managed successfully with ECMO was a victim of a severe blunt trauma [1]; however, throughout the 1980s, major trauma remained a relative contraindication for ECMO due to the need for therapeutic anticoagulation and risk of hemorrhagic complications [5]. During the 1990s, several case series

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demonstrated a modicum of success managing respiratory failure after trauma with ECMO [5, 6], suggesting a possible role for expanded application of ECMO in this patient population. Over the last two decades, outcomes among patients with major trauma receiving ECMO have improved [4, 7]. A variety of ECLS platforms have been used successfully in patients with traumatic injuries and different etiologies of cardiopulmonary failure [5, 6, 8, 9]. ECMO for traumatic injury and respiratory failure characterizes the most robust experience reported in the literature and the most common application of ECLS in patients with major trauma [4]. Therefore, this chapter will focus on ECMO for traumatic injury and respiratory failure.

There are no randomized controlled trials examining ECMO in the trauma population. Several retrospective case series and cohort studies have demonstrated promising outcomes among patients with traumatic injury and respiratory failure receiving ECMO, reporting in-hospital survival rates of 41–89% in patients with high injury severity and physiologic derangement before ECMO initiation [10–12]. For clinicians in the contemporary trauma unit, understanding the indications, management considerations, and evidence for ECMO in patients with traumatic injury and respiratory failure can facilitate the implementation of life-saving technology in this patient population.

Search Strategy

We evaluated the existing literature regarding the efficacy and safety of ECMO in the patient with traumatic injury and respiratory failure. The PubMed database was screened to identify studies meeting the following inclusion criteria: (1) original research, (2) sample population > 5 patients, and (3) patients receiving ECMO for traumatic injury and respiratory failure. We excluded studies that reported outcomes in patients with respiratory failure and burn injury or smoke inhalation, [meta-analyses and systematic] reviews, and publications that did not specify the type of ECLS platform utilized. One publication included patients treated with pumpless extracorporeal lung assist devices [13]; we included only patients treated with ECMO in the outcome analysis. Seventeen original research reports were included in the outcomes analysis for patients with traumatic injury and respiratory failure treated with ECMO. We extracted mean age, sex, initial ECMO mode, type of traumatic injury, duration of ECMO support, length of stay, in-hospital survival, and prevalence of bleeding complications from each study as shown in Table 24.1. Each study was evaluated for quality using the GRADE system. Study characteristics and quality of evidence are shown in Table 24.2. The Patient—Intervention—Comparison—Outcome (PICO) framework, as applied to this patient population is shown in Table 24.3. However, the available evidence in ECMO for patients with traumatic injury and respiratory failure is primarily retrospective and usually does not incorporate comparison cohorts.

Table 24.1 Key clinical characteristics and outcomes among patients with traumatic injury and respiratory failure treated with extracorporeal membrane oxygenation

Study	*N*	Age (years)	Male (%)	Veno-venous ECMO (%)	Traumatic injury	ECMO duration (days)	Length of stay (days)	Survival (%)	Bleeding complications (%)
Ahmad et al. 2017	39	28	72	100	Mixed	13[a], 5.5[b]	41[a], 11[b]	44	41
Anderson et al. 1994	24	27	NR	71	Mixed	12	NR	63	75
Arlt et al. 2010	10	32	80	70	Mixed	5	NR	60	NR
Bosarge et al. 2015	15	36	100	73	Mixed	8	44	87	NR
Cordell-Smith et al. 2006	28	27	86	100	Blunt	6	NR	71	NR
Grant et al. 2018	22	30[c], 37[d]	86[c], 83[d]	72	Mixed	8[c], 12[d]	37[c], 44[d]	43[c], 55[d]	43[c], 42[d]
Guirand et al. 2014	26	33	77	100	Blunt	9	40	58	15
Huang et al. 2019	12	31	92	100	Mixed	NR	46	75	NR
Jacobs et al. 2015	85	29	84	74	Mixed	9	NR	74	29
Kim et al. 2017	9	48	89	100	Mixed	6	58	89	NR
Kruit et al. 2019	52	33	81	96	Mixed	7	NR	85[e], 85[f]	50
Lin et al. 2017	43	37	84	61	Mixed	7	42	52	35
Michaels et al. 1999	30	26	50	60	Mixed	10	NR	50	59
Ried et al. 2013	26	29	92	100	Mixed	6	NR	81	12
Schmidt et al. 2014	146	NR	NR	NR	NR	NR	NR	64	NR
Swol et al. 2018	279	35	78	89	Mixed	9	NR	61	29
Wu et al. 2015	19	41	89	47	Mixed	7	NR	68	NR

Definitions of abbreviations: *NR* Not reported, *ECMO* extracorporeal membrane oxygenation

[a]Among survivors

[b]Among non-survivors

[c]Among pre-advanced extracorporeal membrane oxygenation program group

[d]Among post-advanced extracorporeal membrane oxygenation group

[e]In-hospital survival

[f]6-month survival

Table 24.2 Included studies for extracorporeal membrane oxygenation in traumatic injury and respiratory failure

Study	Journal	Location	Design	Setting	Primary end point	Follow-up	Quality of evidence
Ahmad et al. 2017	J Trauma Acute Care Surg	USA	Retrospective review	Single center	Survival	In-hospital	Low
Anderson et al. 1994	J Trauma	USA	Retrospective review	Single center	Survival	In-hospital	Low
Arlt et al. 2018	Resuscitation	Germany	Retrospective review	Single center	Survival	In-hospital	Low
Bosarge et al. 2015	J Trauma Acute Care Surg	USA	Retrospective case control	Single center	Survival	In-hospital	Low
Cordell-smith et al. 2006	Injury	USA	Retrospective cohort study	Single center	Survival	ICU	Low
Grant et al. 2018	Artif Organs	USA	Retrospective cohort study	Single center	Survival	In-hospital	Low
Guirand et al. 2014	J Trauma Acute Care Surg	USA	Retrospective review	Multi center	Survival	In-hospital	Low
Huang et al. 2019	J Trauma Acute Care Surg	USA	Retrospective cohort study	Single center	Survival	In-hospital	Low
Jacobs et al. 2015	J Trauma Acute Care Surg	International registry	Retrospective review	Multi center	Survival	In-hospital	Low
Kim et al. 2017	Artif Organs	Korea	Retrospective review	Multi center	Survival	In-hospital	Low
Kruit et al. 2019	J Trauma Acute Care Surg	UK	Retrospective cohort study	Multi center	Survival	In-hospital, 6-month	Low
Lin et al. 2017	Medicine	Taiwan	Retrospective cohort study	Single center	Survival	In-hospital	Low
Michaels et al. 1999	J Trauma Acute Care Surg	USA	Retrospective cohort study	Single center	Survival	In-hospital	Low
Reid et al. 2013	Crit Care	Germany	Retrospective cohort study	Single center	Survival	In-hospital	Low
Schmidt et al. 2014	Am J Respir Crit Care Med	International registry	Retrospective cohort study	Multi center	Survival	In-hospital	Moderate
Swol et al. 2018	J Trauma Acute Care Surg	International registry	Retrospective review	Multi center	Survival	In-hospital	Low
Wu et al. 2015	Am J Emerg Med	Taiwan	Retrospective cohort study	Single center	Survival	In-hospital	Low

Definitions of abbreviations: *J Trauma Acute Care Surg* Journal of Trauma and Acute Care Surgery, *Artif Organs* Artificial Organs, *Crit Care* Critical Care, *Am J Respir Crit Care Med* American Journal of Respiratory and Critical Care Medicine, *Am J Emerg Med* American Journal of Emergency Medicine, *USA* United States of America, *UK* United Kingdom

Table 24.3 PICO

Patients	Intervention	Comparator	Outcomes
Trauma and respiratory failure patients	ECMO in trauma and respiratory failure patients	No ECMO in trauma and respiratory failure patients	ARDS, bleeding complications, TBI, morbidity, mortality

Results

Modes and Configurations

Optimal ECMO support for patients with traumatic injury and respiratory failure relies on selecting the appropriate ECMO configuration based on the pathophysiologic needs of the patient. Historically, V-A ECMO was generally the mode of choice for patients with traumatic injuries and respiratory failure [1, 5, 6]. However, V-V ECMO has become the preferred platform for these patients in the modern era [4, 12, 14]. V-V ECMO provides excellent support of the respiratory system with lower risks of bleeding, embolic events, and limb ischemia when compared to V-A ECMO configurations [15]. Even in the presence of concomitant shock, V-V ECMO often remains a safe and effective platform.

We preferentially initiate V-V ECMO for patients with traumatic injury and respiratory failure, even in the presence of severe hemodynamic instability. Generally, hemodynamics improves after initiation of V-V ECMO with correction of acid-base status, improvement in oxygenation, decreased sedation, and reduction of mechanical ventilation pressure. A subset of these patients may continue to require high levels of vasopressor/inotrope support. In these cases, transthoracic echocardiogram and invasive hemodynamic monitoring can be useful in understanding the etiology of ongoing shock. Patients with severe secondary pulmonary hypertension, right ventricular dysfunction, or concomitant cardiomyopathy, may benefit from conversion to a hybrid configuration with additional V-A support [16].

Evidence for ECMO in All-Cause ARDS

All-Cause ARDS Literature

While there are no prospective data examining outcomes of ECMO use in patients with major trauma, there have been two randomized controlled trials over the past decade examining outcomes among adults with ARDS treated with ECMO [17, 18]. In 2009, Peek et al. (CESAR trial) demonstrated a 13% in-hospital survival benefit among patients with ARDS transferred to a specialized ECMO center compared to patients who were managed with usual care at a non-ECMO center [17]. More recently, in the first multicenter randomized controlled trial comparing ECMO to the standard of care for patients with ARDS, Combes et al. (EOLIA trial) demonstrated a 60-day mortality difference in the ECMO group when compared to the group who received the standard of care (35 vs. 46% respectively; relative risk,

0.76; 95% CI, 0.55–1.04; $P = 0.09$), with the option of crossover to ECMO for failure of the standard of care [18]. The trial was stopped early due to futility, as it was unlikely to show efficacy in the ECMO group [18–20]. The interpretation of these data is debated, but many acknowledge that the EOLIA trial data support the use of ECMO for select patients with ARDS, especially when analyzed exclusively of the crossover patients [19–22].

In the CESAR trial, 12/180 patients enrolled had recent traumatic injuries, though outcomes of this subgroup were not reported. Patients with a contraindication to limited anticoagulation or intracranial hemorrhage were excluded [17]. The EOLIA trial did not report the presence of a traumatic injury but did not systematically exclude patients with traumatic injury. Patients with greater than 7 days of mechanical ventilation prior to enrollment were excluded in both trials due to prior work demonstrating poor outcomes among patients with prolonged mechanical ventilation time before ECMO initiation [23, 24]. These trials also excluded patients with devastating neurologic events [17, 18].

Applicability of all-cause ARDS literature to patients with traumatic injury and respiratory failure.

Patients with traumatic injury and respiratory failure introduce unique challenges, such as active bleeding, traumatic brain injury, and frequent need for surgical intervention [25–28]. Further, the biology of traumatic lung injury is different from other common etiologies of lung injury in the general ARDS population [29]. Given the inherent differences between the adult ARDS population and patients with traumatic injury and respiratory failure, the results of the CESAR and EOLIA are unlikely to fully translate to the trauma population. Retrospective data suggest superior outcomes in the use of ECMO for patients with traumatic injury and respiratory failure when compared to the use of ECMO in adults with ARDS unrelated to trauma [4, 30, 31]. We speculate that younger age and fewer chronic comorbidities positively influence outcomes in the trauma and respiratory failure population relative to the general ARDS population [4, 31–34].

Global Indications and Contraindications

Despite the inherent differences between the sample population in the CESAR and EOLIA trials and patients with traumatic injury and respiratory failure, we have gained insight into appropriate selection criteria for patients with acute hypoxemic and/or hypercapnic respiratory failure and can apply these criteria to the trauma population. Inclusion criteria for enrollment represented expert consensus on the physiologic parameters for which ECMO was most likely to confer a survival advantage for patients with ARDS [17, 18]. Criteria for ECMO initiation in patients with ARDS included a ratio of partial pressure of arterial oxygen (PaO2) to the fraction of inspired oxygen (FiO2) of less than 80 mmHg or a pH less than 7.25 with a partial pressure of arterial carbon dioxide (PaCO2) greater than 60 mmHg after maximization of mechanical ventilation without compromising lung protective strategies, and optimization of medical therapies including available rescue

strategies such as neuromuscular blocking agents, inhaled pulmonary vasodilators, and prone positioning [18]. Both trials excluded patients who received greater than 7 days of mechanical ventilation [17, 18] due to prior work demonstrating poor outcomes among patients with prolonged mechanical ventilation before ECMO initiation [5, 6, 23, 24, 30].

Although these physiologic parameters inform patient selection for ECMO in ARDS, each patient and clinical circumstance must be individually evaluated. Underlying physiology, onset and acuity of respiratory failure, and coexisting injuries in the trauma population are diverse and must be carefully considered. A decision-making pathway for patient selection is shown in Fig. 24.1. In the subsequent sections of this chapter, we discuss several of the core considerations for the initiation and management of ECMO in patients with traumatic injury and respiratory failure.

Direct Pulmonary Trauma

The etiology of respiratory failure after major trauma can include traumatic injury to the pulmonary system, chest wall, or a combination of both [13, 35, 36]. Direct pulmonary trauma that can lead to severe respiratory failure includes pulmonary contusion, tracheobronchial disruption, multiple rib fractures, flail chest, massive hemoptysis, pulmonary laceration, bronchopleural fistula, and blast lung injury [13, 36–39]. Each is a potentially reversible cause of respiratory failure, requiring time and supportive care, but may also necessitate surgical intervention [36, 40, 41].

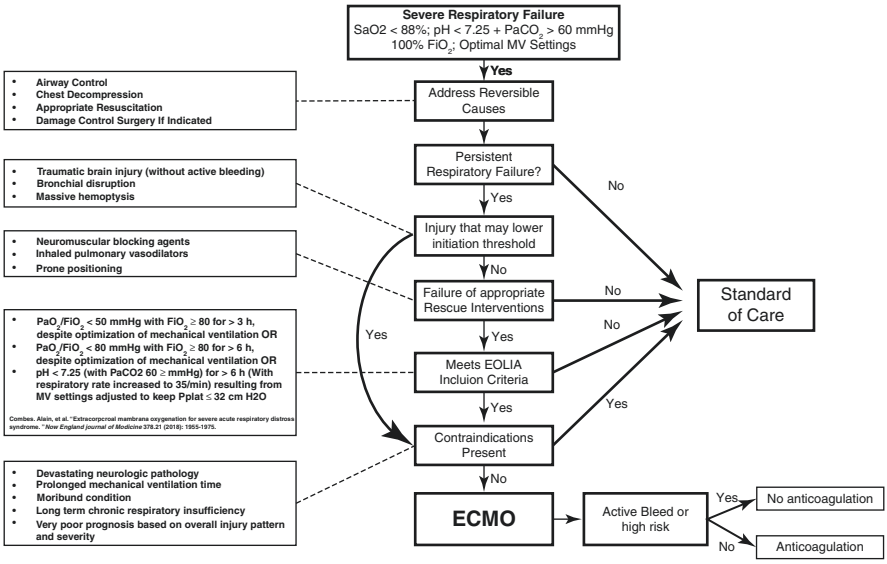

Fig. 24.1 Decision-making pathway for patients with traumatic injury and respiratory failure

Conventional mechanical ventilation strategies and rescue therapies may be insufficient to physiologically support the patient. In these clinical circumstances, ECMO can be a life-saving support device for bridging these patients to recovery or intervention [36, 38].

While the previously described initiation criteria for ECMO in severe hypoxemic and hypercapnic respiratory failure form the foundation of our decision-making approach, certain etiologies of direct pulmonary trauma alter our criteria to initiate ECMO. High-pressure mechanical ventilation is particularly deleterious to patients with pulmonary lacerations, bronchopleural fistulas, and blast lung injuries. Avoidance of high airway pressure may be useful in facilitating recovery [36, 42]. Therefore, liberalizing selection criteria for ECMO initiation in these pathologies may be reasonable, although data are lacking.

Finally, some patients with direct pulmonary trauma can present with a profound inability to oxygenate or ventilate. Examples in which emergent initiation of ECMO support may be life-saving include bronchial disruption and massive hemoptysis [38, 39, 41]. ECMO initiation should not supplant the advanced trauma life support approach to the management of acute respiratory failure. Once the airway is secured and the chest has been decompressed bilaterally, it may be reasonable to consider the initiation of ECMO emergently. Existing literature is limited to case reports and series for ECMO in direct pulmonary trauma and the overall quality of evidence is low [39, 41].

Hemorrhage, Thrombosis, and Anticoagulation Management

Bleeding complications have historically limited the utilization of ECMO for patients with traumatic injuries and respiratory failure [1, 5]. Patients receiving ECMO are also at increased risk for thrombotic complications [43]. Systemic anticoagulation is currently the standard practice for patients receiving ECMO to preserve circuit patency and reduce thrombotic and embolic complications [44, 45]. Circuit technology has improved over time, and the risk of circuit-related thrombotic events has decreased [7, 46]. The benefits of anticoagulation relative to the risks of exacerbation of hemorrhagic complications must be weighed, particularly in patients with increased risk of hemorrhage [44, 47, 48]. Evaluating risk for hemorrhagic and thrombotic complications is paramount to informing anticoagulation management for patients receiving ECMO.

Patients with traumatic injuries may present with active hemorrhage and respiratory failure. The ability to provide adequate physiologic support with ECMO depends on sufficient intravascular volume to ensure adequate blood flow through the membrane oxygenator. Hemorrhagic shock can limit the efficacy of ECMO support for these patients [49]. However, there have been case series describing the successful implementation of ECMO for patients with traumatic injuries and hemorrhagic shock, and we do not consider active massive hemorrhage to be an absolute contraindication to ECMO initiation [25]. The extent of hemorrhage and blood product requirements at the time of initiation are likely to impact overall survival,

and should be considered in the context of the clinical circumstance [12, 49]. ECMO initiation should not delay interventions to control active hemorrhage and can be implemented at the time of damage control surgery [9, 25].

New bleeding complications and exacerbation of bleeding impact morbidity and mortality for patients receiving ECMO [15, 48, 50]. Etiologies of bleeding complications in victims of major trauma include exacerbation of injury site or surgical site bleeding, cannula sites, spontaneous retroperitoneal, abdominal solid organs, gastrointestinal, nares, and intracranial hemorrhage [15, 50]. ECMO increases bleeding risk due to circuit-related coagulopathy and the use of systemic anticoagulation [48, 51, 52]. On the other hand, ECMO may assist in correcting trauma-related coagulopathy by improving acidosis and temperature control44. The prevalence of bleeding in several retrospective case series and cohort studies was 12–75% [5, 6, 53], as shown in Table 24.1. The studies that reported bleeding complication rates of 59 and 75% were published over 20 years ago and employed higher anticoagulation parameters [5, 6]. The majority of reported bleeding complications were minor and did not require intervention [44]. However, red blood cell transfusion requirements while receiving ECMO appeared to negatively impact in-hospital survival [50]. The time from injury to ECMO initiation is likely inversely related to the risk for bleeding complications [44, 48].

Patients receiving ECMO are also at risk for thrombotic complications including circuit thrombosis, pump or oxygenator failure, and cannula-associated deep venous thrombosis (DVT). Total circuit thrombosis is uncommon [45, 50]. Pump or oxygenator failure requiring replacement is slightly more common, though rarely clinically meaningful [15, 44, 51]. Improvements in technology, including biologically coated circuits and oxygenators, may reduce circuit-related thrombotic events and decrease the degree of systemic anticoagulation required, though data are limited and this remains unclear [46]. Cannula-associated DVT is particularly common in patients supported with ECMO. In a recent retrospective cohort study of patients supported with V-V ECMO, 41/48 (85.4%) patients developed cannula-associated DVT identified by routine surveillance ultrasound of upper and lower extremities following decannulation [43]. However, none of these patients developed evidence of pulmonary embolism. The patients in this cohort were anticoagulated with a Heparin infusion for a goal activated partial thromboplastin time of 45–55 s unless an indication for therapeutic anticoagulation was present [43]. Not surprisingly, the reported incidence of cannula-associated DVT is markedly lower in the absence of routine surveillance [44]. The impact of anticoagulation parameters and the clinical significance of cannula-associated DVT are unclear [44].

Management of systemic anticoagulation for patients treated with ECMO for respiratory failure after trauma is challenging due to the risks of hemorrhagic and thrombotic complications. High-quality available data are limited and practice patterns are variable [10, 14, 34, 53]. Heparin infusion titrated to an activated partial thromboplastin time of 40–60 s or anti-Xa activity level of 0.2–0.4 IU per mL is a common practice in patients without active hemorrhage or severe coagulopathy [18, 50]. The optimal anticoagulant drug, monitoring laboratory tests, and anticoagulation level are not known. Over the last decade, several case series and retrospective

cohort studies have described the use of minimal or no systemic anticoagulation in patients receiving ECMO for traumatic injuries and respiratory failure [12, 25, 54, 55]. These data and anecdotal experiences suggest that the risk of bleeding can outweigh risks of thrombotic complications in certain patients [10, 44]. While data are lacking, select patients likely benefit from ECMO despite contraindications to systemic anticoagulation [44, 54, 55].

We use limited heparin anticoagulation (activated partial thromboplastin time goal of 40–60 s) in patients at low risk for hemorrhage. We do not consider underlying coagulopathy and high risk for hemorrhage to be absolute contraindications to ECMO for patients with traumatic injuries and respiratory failure but would abstain from using systemic anticoagulation in these patients. We perform routine upper and lower extremity ultrasounds to evaluate for cannula-associated DVT 48–72 h following decannulation and treat identified DVTs with 3 months of systemic anticoagulation if not otherwise contraindicated.

ECMO for Traumatic Brain Injury and Respiratory Failure

Respiratory failure is a known complication of traumatic brain injury (TBI) and negatively impacts overall survival and long-term neurologic outcomes [27, 56]. Historically, TBI has been considered a relative contraindication for ECMO due to the need for systemic anticoagulation to maintain circuit patency and the risk of intracranial hemorrhage progression [5, 6, 17]. Advances in circuit and oxygenator technology may reduce requirements for systemic anticoagulation and ameliorate risks of worsening intracranial hemorrhage [44]. In a systematic review, Bedeir et al. identified 23 patients with traumatic intracranial hemorrhage who were supported with ECMO. Nineteen of 23 patients survived; no deaths were related to increased intracranial bleeding [26]. Lower risk profiles and tolerance of minimal or no anticoagulation with modern ECMO circuits allow for a more liberal application of ECMO for patients with TBI and respiratory failure. The evolving indications for ECMO in this patient population warrant particular consideration.

The use of ECMO in patients with recoverable TBI and respiratory failure may improve both survival and long-term neurologic outcomes by mitigating secondary neurologic injury from hypoxemia and hypercapnia in select clinical circumstances [55, 57, 58]. Neurologic prognosis is fundamental to patient selection. ECMO initiation in patients with devastating neurologic injuries may prolong suffering and reduce access to a limited resource to those more likely to benefit. For patients with a recoverable brain injury, preventing secondary brain injury is the cornerstone of TBI management [58, 59]. Both hypoxemia and hypercapnia impair cerebral oxygen delivery. Conventional mechanical ventilation strategies and rescue therapies for respiratory failure such as permissive hypercapnia, high PEEP, and prone positioning may worsen cerebral perfusion. Further, deep sedation and neuromuscular blocking agents limit the ability to monitor the patient's neurologic exam. ECMO can facilitate target oxygenation saturation and arterial carbon dioxide goals while allowing a reduction in injurious ventilator settings and sedation, and upright patient

positioning [57]. For these reasons, recoverable TBI lowers our threshold for initiating ECMO for respiratory failure. We may elect to initiate ECMO prior to exhausting oxygenation and ventilation rescue strategies that might exacerbate secondary brain injury. However, practical clinical reasoning and experience drive this practice, rather than high-quality data.

Respiratory Failure After Burn Injury

Respiratory failure can occur after burn injury via direct insult to the lung due to smoke inhalation, inflammatory response, or associated infection [60]. ECMO may be useful in select cases. Data in patients with burn injury are limited to retrospective cohorts and case series, and results are variable [61–64]. For example, Soussi et al. reported 28% 90-day survival in a series of 11 patients with burn injury and ARDS, while Eldredge et al. reported a case series of 8 patients in-hospital survival 87.5% [61, 63]. Ainsworth et al. reported a 57% in-hospital survival in a series of 14 patients with burn inhalation injury, or toxic epidermal necrolysis syndrome and ARDS. The average TBSA in the 11 patients with thermal burns was 27% and 8/11 had partial or complete excision and grafting prior to ECMO initiation [64].

Patients with less TBSA burn and less severe inhalation injury have a better prognosis regardless of ECMO, and it is unclear from available data whether ECMO provides a survival benefit in this context [65]. Size of burn, timing of ECMO relative to excision and grafting, and the presence of inhalation injury should inform candidacy for ECMO in respiratory failure after burn injury. In our experience, patients with large TBSA burns that are un-excised present particular challenges for management with ECMO. ECMO increases the risk of bleeding by the mechanisms previously described, complicating large burn excisions. We caution ECMO initiation in patients with large un-excised burns and those with high predicted mortality based on the overall burden of burn and inhalation injury.

Operative Procedures on ECMO

A major concern for trauma clinicians is the ability to perform necessary, and often frequent, operative procedures on trauma patients receiving ECMO. Several retrospective case series have documented operative procedures performed in patients receiving ECMO for traumatic injury and respiratory failure [6, 13, 35, 44]. Although there are reported bleeding complications after operative procedures during ECMO, the rates of complications are not prohibitively high in these limited datasets [35, 44]. Neurosurgical intervention, laparotomy, thoracotomy, orthopedic procedures, and tracheostomy have all been safely performed on patients receiving ECMO, respectively [6, 13, 38, 66, 71]. In our practice, recent surgery and the need for future intervention are not contraindications to ECMO initiation. However, performing invasive procedures during ECMO is carefully considered, and unnecessary procedures are avoided to reduce bleeding complications when possible.

ECMO Transport

Treatment of patients with severe injuries at designated trauma centers likely reduces mortality, but this is not always realistic as patients often present to a medical facility nearest to the scene of traumatic injury for triage and initial resuscitation [67]. Safe transport to a specialized center is important for ensuring the best possible outcome for patients with severe traumatic injuries. Initiation of ECMO outside of specialized centers and transport of patients during ECMO support have been shown to be safe and effective [68–70]. Severe respiratory failure may compromise the ability to safely transport patients with traumatic injuries. While ECMO may benefit these patients, it requires resources limited to specialized centers [17]. Interfacility transport of patients with ECMO can make this potentially life-saving technology available to patients who initially presented to a center without ECMO capabilities [68]. ECMO can also enable transport of patients who are otherwise too unstable to move, allowing treatment of these patients at a facility most equipped to care for their pathology. Even in uniquely austere environments, such as forward military bases initiation of ECMO can be considered to enable safer transport of patients with traumatic injury and respiratory failure [37, 69, 70].

Recommendation Based on the Data

There are no prospective randomized controlled trials evaluating ECMO for patients with traumatic injury and respiratory failure. Available data are limited to retrospective case series and cohorts. The mean in-hospital survival among 879 patients within the 17 studies was 66.5%. This rate is comparable, and slightly superior, to the 58% in-hospital survival reported by the Extracorporeal Life Support Organization Registry for all-cause adult respiratory failure over 27 years [3]. Therefore, the effectiveness of ECMO compared to conventional therapy for respiratory failure in patients with a traumatic injury cannot be determined. Promising outcomes found in retrospective data suggest that ECMO may be a life-saving intervention for appropriately selected patients with traumatic injury and respiratory failure. However, randomized controlled trials comparing treatment with ECMO to conventional management strategies in this population do not exist. Thoughtful clinical judgment is required to select trauma patients most likely to benefit from ECMO and appropriately manage them while receiving extracorporeal support.

Summary of Recommendations

- No recommendation for the use of Extracorporeal Membrane Oxygenation (ECMO) for support of patients with traumatic injury and respiratory failure can be made. (evidence quality low; No recommendation).

A Personal View of the Data

In the absence of a randomized controlled trial for ECMO use in patients with traumatic injury and respiratory failure, we cannot determine whether these patients benefit from ECMO. Circuit technology, cannulation technique, and management strategies have evolved since the publication of many studies presented in this chapter, and we advise caution when interpreting older results. ECMO is a device that improves oxygenation and carbon dioxide clearance in patients with respiratory failure refractory to mechanical ventilation and rescue interventions [19]. Our experience suggests that ECMO has an important role in the management of select patients with traumatic injury and respiratory failure. We encourage continued application of ECMO in this population, and a commitment to ongoing evaluation of efficacy, safety, and outcomes.

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Is There a Gold Standard for Screening Blunt Cardiac Injury?

25

Andrew J. Benjamin and Selwyn O. Rogers

Introduction

The frequency of cardiac injury in blunt trauma varies significantly in the literature, and estimated that 0.3% of all trauma admissions present with a blunt cardiac injury (BCI) [1]. Blunt cardiac injury encompasses a wide range of presentations and clinical manifestations, ranging from cardiac rupture resulting in death at the scene, to asymptomatic "contusion." Additionally, autopsy reports suggest a 10–32% rate of cardiac injury in blunt traumatic fatalities, with 65% of cardiac injuries being cardiac rupture [2–4]. The majority of significant cardiac injuries die in the field with less than 5% of fatally injured patients surviving to hospital admission [5]. As such, most patients with BCT who present to the hospital are likely to have more minor injuries, however, it is important to have a high suspicion for a significant injury, as a delay in diagnosis can be quickly fatal and the injury can be salvaged.

Given the potentially severe consequences of a missed blunt cardiac injury, it is imperative that significant injuries be promptly recognized and treated. However, given the varying presentation as well as lack of Level I evidence, few cohesive and comprehensive guidelines exist to guide practice.

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Search Strategy

A literature search was conducted using the databases PubMed and Embase for the period 1990 through 2020 for articles published in English. Search terms included combinations of: Blunt OR non-penetrating; cardiac OR myocardial OR heart; injury OR trauma OR contusion OR concussion. Articles were selected that included data by which sensitivity and/or specificity could be calculated for the tests included in the PICO question (Table 25.1). Review articles and meta-analysis articles were reviewed and also were scanned to ensure that all appropriate publications were included.

Results

Screening for Blunt Cardiac Injury

Blunt Cardiac Injury (BCI), formerly also known as cardiac contusion/concussion, requires a high index of suspicion to not miss severe cases associated with cardiac failure or conduction abnormalities. Many patients with significant BCI are already admitted to an intensive care setting due to additional injuries. However, the degree of testing required in patients who are otherwise hemodynamically normal and would not require more intense monitoring is an area of debate (Table 25.2). A cost-effective and evidence based approach is necessary to correctly identify low-risk patients who can be safely discharged home.

In 1998 the Eastern Association for the Surgery of Trauma (EAST) published the first practice management guidelines related to screening patients for BCI [6]. It established ECG as the most important and only necessary test in ruling out significant BCI in a hemodynamically stable patient (Level I). Alternatively, for a hemodynamically stable patient with an abnormal ECG, it was proposed that the patient be admitted for 24–48 h of telemetry monitoring.

Following publishing of the initial guidelines, several studies questioned whether a normal ECG in isolation was sufficient for ruling out BCI. Garcia-Fernandez et al. performed a multi-center prospective study which investigated the use of TEE in patients presenting with blunt thoracic trauma. TEE was compared to ECG and troponin, and although ECG abnormalities were more frequent in patients with pathologic TEE findings, 41% of patients with a significant TEE finding had a normal ECG. More concerning, four of 6 patients with a life-threatening BCI had

Table 25.1 PICO formatted terms for literature search

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with blunt thoracic trauma	Screening with EKG, troponin, and echocardiogram	No screening	Detection of blunt cardiac injuries

Table 25.2 Studies evaluating tests to rule out blunt cardiac injury

Study and year	Study design	Tests	Results
Heidelberg et al. (2019)	Retrospective	EKG	EKG: Sensitivity (98%), specificity (100%)
Sade et al. (2017)	Prospective	EKG, CT	EKG: Sensitivity (71%), specificity (N/A) CT: Sensitivity (82%), specificity (N/A)
Burrell et al. (2017)	Prospective	EKG, Trop, Echo, MRI	EKG: Sensitivity (43%), specificity (81%) Echo: Sensitivity (19%), specificity (100%) MRI: Sensitivity (29%), specificity (100%)
Hammer et al. (2016)	Retrospective	EKG, Trop, Echo, CT	EKG: Sensitivity (76%), specificity (N/A) Trop: Sensitivity (57%), specificity(N/A) Echo: Sensitivity (50%), specificity (N/A) CT: Sensitivity (22%), specificity (N/A)
Namrata et al (2015)	Prospective	EKG, Trop, Echo	EKG: Sensitivity (93%), specificity (45%) Trop: Sensitivity (40%), specificity (89%) Echo: Sensitivity (50%), specificity (N/A)
Emet et al. (2010)	Retrospective	EKG, Trop, Echo	EKG: Sensitivity (54.5%), specificity (74.2%) Trop: Sensitivity (68.2%), specificity (100%) Echo: Sensitivity (0%), specificity (100%)
Velmahos et al. (2003)	Prospective	EKG, Trop, Echo	EKG: Sensitivity (89%), specificity (67%) Trop: Sensitivity (73%), specificity (60%) Echo: Sensitivity (50%), specificity (100%)
Salim et al. (2001)	Prospective	EKG, Trop, Echo	EKG: Sensitivity (77%), specificity (53%) Trop: Sensitivity (68%), specificity (85%) Echo: Sensitivity (47%), specificity (100%)
Mori et al. (2001)	Prospective	Echo	Echo: Sensitivity (35%), specificity (100%)

(continued)

Table 25.2 (continued)

Study and year	Study design	Tests	Results
Bertinchant et al. (2000)	Prospective	EKG, Trop, Echo	EKG: Sensitivity (73%), specificity (96%) Trop: Sensitivity (23%), specificity (97%) Echo: Sensitivity (42%), specificity (100%)
Boeken et al. (2000)	Retrospective	Echo	Echo: Sensitivity (41%), specificity (N/A)
Garcia-Fernandez et al. (1998)	Multi-center prospective	EKG, Echo	EKG: Sensitivity (72%), specificity (81%) Echo: Sensitivity (56%)
Adams et al. (1998)	Prospective	EKG, troponin	Trop: Sensitivity (100%), specificity (97%)
Fulda et al. (1997)	Prospective	EKG, Trop, Echo	EKG: Sensitivity (38%), specificity (93%) Trop: Sensitivity (27%), specificity (91%) Echo: Sensitivity (12%), specificity (98%)
Biffl et al. (1994)	Retrospective	EKG, Echo	EKG: Sensitivity (84%), specificity (100%) Echo: Sensitivity (31%%), specificity (N/A)
Fabian et al.	Prospective	EKG	EKG: Sensitivity (68%), specificity (73%)
Wisner et al. (1990)	Retrospective	EKG, Echo	EKG: Sensitivity (24%), specificity (100%) Echo: Sensitivity (33%), specificity (85%)

EKG electrocardiogram, *TROP* troponin, *Echo* echocardiogram

normal ECGs. Subsequently, three additional studies also determined that a subset of patients would develop a clinically significant abnormality who presented with a normal ECG, despite a negative predictive value of 95–98% [7–9]. As such, in 2012 EAST revised the practice management guidelines [10]. Although an admission ECG remains the only Level I recommendation for screening patients in whom BCI is suspected in the most updated guidelines, the new guidelines reflect the fact that ECG alone is often not sufficient to completely rule out clinically significant BCI.

Initially, serum cardiac assays were thought to be a potentially useful adjunct in the diagnosis of BCI, however early studies suggested no benefit in screening patients with blunt thoracic trauma. Biffl et al. performed a retrospective review over 4 years and determined that cardiac enzymes were "irrelevant" in ruling out BCI [11]. In their study, 30% of high-risk patients were determined to have BCI, with ECG being the most significant independent predictor of adverse events, although a subset of patients who had adverse events presented with a normal admission ECG. Isolated troponin elevations did not predict complications, as all

patients with an elevated troponin who had a complication presented with an abnormal ECG as well. Bertinchant et al. performed a prospective study to evaluate the value of checking troponin in hemodynamically stable patients with blunt chest trauma. In isolation, they found troponin to be highly specific, but only 23% sensitive [12]. The initial EAST guidelines did not recommend checking serum cardiac markers, however, upon revision in 2012, several prospective studies by Salim et al. and Velmahos et al. had found diagnostic synergy between ECG and cardiac troponin when used in combination, with a negative predictive value of 100% [8, 9]. Therefore, the most recent guidelines have a Level III recommendation to routinely measure Troponin T, and admit to a monitored setting if elevated while checking serially [10].

High-sensitivity cardiac troponin (hs-cTn) assays were approved in the United States in 2017 and are able to detect myocardial injury at lower concentrations, as well as discriminate small changes in concentration when compared to traditional troponin assays. All previous studies and guidelines have based their outcomes and guidelines on non-high-sensitivity troponin levels, and, therefore, the predictive value of elevated hs-cTn is unknown. Keskpaik et al. [13] performed a retrospective review which identified 147 consecutive patients with severe chest trauma from 2015 to 2017 and found that patients with elevated hs-cTn had higher in-hospital mortality (26 vs. 4%), increased ventilator days, and worse Glasgow Outcome Scale scores. Although this study showed worse outcomes related to elevated hs-cTn, it did not evaluate its usefulness as a screening tool for significant BCI, especially in comparison to traditional serum cardiac troponin assays.

Transthoracic echocardiography (TTE) is a useful adjunct in the workup of BCI, as it provides a means of directly visualizing structural abnormalities as well as assessing ventricular function which may be vital in guiding treatment of severe BCI. Multiple studies have shown that echocardiographic findings are associated with BCI related complications [14, 15]; however, it also appears to have a lower sensitivity than either ECG or troponin [16]. Van Lieshout et al. [17] showed in a recent meta-analysis that TTE has a pooled sensitivity for ruling out BCI of only 45%. Although it is not a highly sensitive test useful in screening for BCI, echocardiography had a specificity of 88%, the highest of any diagnostic test evaluated. Prior studies by Skinner et al. [18] found that 79% of patients on whom TTE was performed had abnormal findings and Ferrada et al. [19] found that early, limited TTE was useful in guiding management. In patients who presented with hypotension, TTE changed management in 65% of patients who were over age 65.

Transesophageal echocardiography (TEE) provides better imaging of cardiac structures and more complete evaluation for BCI when compared to TTE, with significantly improved evaluation of ventricular and valvular function. Prospective studies have compared patients undergoing TTE as well as TEE, and found that TEE provides superior diagnostic capabilities [20–22]. In addition, in one study TEE identified multiple serious injuries that were not detected with TTE [23]. Despite its advantages, it is not routinely used due to being resource intense and invasive in nature, however can be useful in the right clinical context.

Historically, computed tomography (CT) was considered an unreliable exam in the diagnosis of BCI. Vignon et al. compared CT scan and TEE prospectively in 110 consecutive patients with blunt trauma. Although both modalities identified the one patient with hemopericardium, CT missed four cases of myocardial contusion and one case of cardiac thrombus, all of which were identified by TEE [24]. For that reason, helical CT was not thought to be useful in the workup of BCI. However, starting around 2002, multidetector CT technology became available with improved resolution and ability to evaluate for cardiac injuries. Since that time, several observational studies have evaluated the role of CT scan in diagnosis and screening for BCI. Hammer et al. retrospectively identified 42 patients who were diagnosed with BCI and had a chest CT within 10 days of presentation. 82% of patients who had a combination of ECG, troponin, and echocardiographic abnormalities also had abnormalities on CT scan. However, of patients with echocardiographic wall motion abnormalities, no right ventricular injuries and only 22% of left ventricular injuries were identified on CT [25]. Sade et al. prospectively assessed the use of dual-energy CT (DECT), which can more accurately assess cardiac perfusion defects and function, to identify BCI. 17 consecutive patients with an abnormal admission ECG, elevated troponin, but a normal TTE were assessed using DECT. Sensitivity of DECT was 82%, and the one patient who went on to develop myocardial failure had a contusion that affected most of the myocardium.

Magnetic resonance imaging (MRI) has been shown to be effective in diagnosing a variety of functional and structural cardiac abnormalities [26]. Although numerous case reports exist regarding the use of MRI in the workup of BCI [27–29], only one prospective trial has been performed to date. Burrell et al. compared 21 patients with major chest trauma and elevated troponin to patients without chest trauma. Overall, cardiac MRI performed within 7 days of injury was 29% sensitive and 100% specific in ruling out BCI. However, it was 60% sensitive and 81% specific for predicting major adverse cardiac events (MACE), defined as malignant arrhythmia, hypotension requiring inotropes, or injuries requiring cardiac surgery [30]. Abnormal troponin or EKG were more sensitive for ruling out MACE, however, cardiac MRI was the most specific (80% compared to 77% for echocardiogram).

Use of FAST

Initial evaluation for blunt cardiac injury begins with a focused assessment with sonography in trauma (FAST) exam during the initial trauma survey. The cardiac portion of the FAST exam evaluates for pericardial fluid as well as cardiac activity [31], and in the hands of experienced users, FAST has been shown to be able to accurately identify pericardial fluid [32] suggestive of cardiac injury. The vast majority of patients with a significant cardiac injury due to blunt trauma die prior to presentation to the trauma bay; however, cardiac FAST is integral in expediting the initial evaluation and management of the small number of patients who survive long enough to receive definitive care.

The utility of cardiac ultrasound in penetrating trauma has been well established in improving time to operative care and mortality [33, 34]. However, although a complete FAST exam is routinely performed at the majority trauma centers for blunt mechanisms, the benefit of routine cardiac FAST in blunt trauma is less well understood. Given the rarity of patients with significant blunt cardiac injuries surviving to emergency room presentation, evidence for cardiac FAST in blunt trauma consists of mostly case reports and small case series. Kato et al. reported a series of patients with blunt trauma with eight patients with blunt cardiac rupture (out of nine with effusion detected by ultrasound) out of 1424 ultrasounds performed between 1985 and 1995 [35]. Symbas et al. described four consecutive cases of patients presenting with blunt cardiac rupture and hemopericardium detected on cardiac ultrasound, with three of the four patients surviving [36].

Although the echocardiographic portion of the FAST exam is routinely performed and recommended by guidelines, little evidence exists to support its routine use. Press et al. performed a retrospective review of 29,236 patients at an urban Level I trauma center over an 8.5 year period and identified 18 patients with hemopericardium or cardiac rupture (14 and 4 patients). In this study, the prevalence of cardiac injury was 0.06% while the prevalence of discovering an incidental or insignificant effusion was double that at 0.13%. All patients with blunt hemopericardium or cardiac rupture presented with either a major mechanism of injury, hypotension, or emergent intubation. This study suggests that cardiac ultrasound should be reserved for cases where risk factors for significant cardiac injury are present, as the low rate of clinically significant injuries may lead to unwarranted intervention when insignificant effusions are found. However, the retrospective nature of the study means that further studies are necessary to determine the correct patient population for routinely performing cardiac ultrasound in blunt trauma. At present time, cardiac FAST results should be interpreted within the clinical context of a patient's presentation.

Treatment of BCI

Given the rarity as well as considerable variation in presentation of clinically significant BCI, the majority of evidence for specific treatment consists of case reports or small case series. The principles of treatment involve admission for monitoring, and supportive care of clinically significant manifestations that arise.

A spectrum of conduction abnormalities are associated with BCI, however, excluding sinus tachycardia or bradycardia which may be associated with a number of causes in the polytrauma patient, right bundle branch block and atrial fibrillation are the most common finding on ECG [37, 38]. When BCI is identified, approximately 25% of patients will require intervention for an arrhythmia [39]. Treatment of conduction abnormalities involves use of antiarrhythmics, but there is no evidence to support the use of one agent over another in the context of BCI. However, there is evidence to suggest that it is important to treat any arrhythmias that do arise.

In a study of 210 patients with BCI, patients with atrial arrhythmias that were treated with a beta-blocker had 15% decreased risk of mortality (22 vs. 37%) [38]. In addition to antiarrhythmics, correction of electrolytes, acid base status, and potentially defibrillation following advanced cardiac life support (ACLS) protocols are all important adjuncts to treatment. Rarely, BCI may present with malignant ventricular arrhythmias [40] for which urgent defibrillation is required [40, 41] or complete heart block requiring cardiac pacing [42, 43]. Patients who present with ST elevations warrant careful consideration, as ST elevations can be related to contusion, however they may also be secondary to coronary rupture, dissection, thromboses, or pre-existing cardiac disease. No standardized approach or guidelines exist, however some experts recommend coronary angiography for all BCI patients with ST elevations [44].

In addition to conduction abnormalities, BCI may present with ventricular wall motion abnormalities, potentially resulting in hemodynamic compromise. The approach to BCI with abnormalities in ventricular function involves supportive care. In cases of severe dysfunction with resulting cardiogenic shock, vasopressors and inotropes may be necessary to preserve cardiac function. Although rare, severe cardiac depression resistant to inotropic support may occur necessitating mechanical support. No large-scale retrospective or prospective studies have been performed; however, there are a number of case reports in the literature describing the use of mechanical support in severe BCI with intra-aortic balloon pump (IABP) placement [45–48].

Most structural injuries such as wall rupture, septal rupture, valve disruption, or pericardial rupture require operative repair. However, surgical intervention for structural abnormalities is extremely rare, as it is estimated from autopsy studies that 78% of patients with blunt cardiac rupture die at the scene and 22% die en route to the hospital [2]. Hemodynamically unstable patients with a positive cardiac FAST should proceed immediately to the operating room for a pericardial window and possible sternotomy. Patients who present with a positive FAST in extremis or who suffer a traumatic arrest in the emergency room should undergo emergency department thoracotomy with opening of the pericardium to relieve tamponade. The use of extracorporeal membrane oxygenation (ECMO) for cardiac repair after blunt cardiac rupture has been reported, even before release of cardiac tamponade [49].

There are few studies which address the long-term consequences of BCI. Lindstaedt et al. found normalization of echocardiographic findings and no cardiac limitations in 12-month follow-up of 118 patients with cardiac contusion [50]. Additionally, Burrell et al. performed cardiac MRI 9 months post-injury and found that three of four patients had persistent evidence of scar. However, no patients had any clinically significant cardiac events or hospitalizations in the 9 months following their initial presentation [30]. Further studies are necessary to determine if a subset of patients with BCI should be followed long-term or have additional workup after discharge.

Recommendations Based on the Data

Given the lack of evidence, the mainstay of BCI management is supportive care. Patients with blunt chest trauma and concern for BCI should be screened with ECG and troponin. Hemodynamically stable patients with normal ECG and troponin need no further workup. Patients with an abnormal ECG, elevated troponin, or both, should be admitted for telemetry monitoring for 24 h. If the admission troponin is elevated with an arrhythmia and/or hypotension, further workup is required. Although it is not necessarily useful as a screening tool, TTE is highly sensitive, and if available, provides critical information regarding the nature and functional consequences of the BCI which can help guide management. CT and MRI may provide potentially useful information, but they should not be routinely performed for the sole reason of diagnosing BCI, but should only be considered on a case by case basis, or be used in the context of workup of other injuries, such as the use of an initial CT "traumagram." Treatment of malignant arrhythmias and cardiogenic shock should proceed per usual care. In cases of severe cardiogenic shock or blunt cardiac rupture, mechanical support with IABP and ECMO has been described, and should be used based upon each individual institutions' available resources.

Summary of Recommendation Options

- Patients with blunt chest trauma and concern for BCI should be screened with ECG and troponin. Hemodynamically stable patients with normal ECG and troponin need no further workup (evidence quality moderate; strong recommendation).
- Patients with an abnormal ECG, elevated troponin, or both should be admitted for telemetry monitoring for 24 h (evidence quality moderate; strong recommendation).
- Patients with clinically significant BCI, such as ongoing arrhythmia and/or hypotension, require further workup. TTE is highly sensitive, and provides critical information regarding the nature and functional consequences of the BCI which can help guide management (evidence quality moderate; moderate recommendation).
- CT and MRI should not be routinely performed for the sole reason of diagnosing BCI. CT and MRI should only be used in the context of workup of other injuries, such as the use of an initial CT "traumagram" (evidence quality low; weak recommendation).
- In cases of severe cardiogenic shock or blunt cardiac rupture, mechanical support with IABP and ECMO has been described, and should be used based upon each individual institutions' expertise (evidence quality low; weak recommendation).

A Personal View of the Data

BCI remains a controversial topic, as the exact terminology and requirements for diagnosis are not well established making it difficult to interpret the available data. However, it is important for the trauma surgeon to understand the role of available diagnostic modalities, as the sensitivity and specificity vary greatly, making each test useful in specific circumstances.

Testing in the context of BCI should generally be used to categorize two groups of patients. The first is a patient with otherwise minor injuries that sustained blunt thoracic trauma who would otherwise be discharged or admitted to the floor without monitoring. Although ECG has consistently been shown to be the best single overall predictor of BCI, numerous studies have shown that ECG combined with troponin has a negative predictive value approaching 100%. Therefore, both should be obtained on presentation for any patient presenting with blunt thoracic trauma prior to determining a disposition. In patients who screen positive, at least 24 h of monitoring is indicated, as significant injuries including malignant arrhythmias and even delayed cardiac rupture with tamponade have been shown to develop in a delayed fashion.

The second group of patients are those with significant polytrauma who develop unexplained hemodynamic instability. It is important to maintain a high index of suspicion for BCI in this patient population, as hemodynamic instability may be easily attributed to other injuries.

- In critically ill, traumatically injured patients who have a positive ECG or troponin, further evaluation with TTE is appropriate.

TTE is a sensitive test that can definitively diagnose BCI, while at the same time providing valuable information regarding cardiac function, the presence of pericardial fluid, or structural abnormalities such as septal defects or valvular abnormalities. Although CT and MRI have shown some capability to diagnose and characterize BCI, they are less cost effective and require transport to less monitored settings. As such, further study is necessary to determine if either provides clinically relevant information beyond ECG, troponin, and echocardiography which are readily available and can be obtained at the bedside. Until then, axial imaging for BCI should only be used when obtained for workup of other injuries or in specific instances in stable patients.

- Given the rarity of clinically significant BCI, no good data exists to guide specific treatments.

The range of presentations varies widely, and other than patients who present with hemodynamic compromise and a positive FAST who require urgent operative intervention, treatment should proceed expectantly. Antiarrhythmics, vasopressors, inotropes, and even mechanical support should be utilized based on local practice patterns, capabilities, and consultation with cardiac specialists.

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Optimal Chest Tube Size for Hemothorax Evacuation

26

Asanthi Ratnasekera and Paula Ferrada

Introduction

Blunt and penetrating thoracic injuries are common. Injuries to the chest occur in approximately 60% of polytrauma patients. Surgical intervention is infrequent in many cases of blunt chest trauma. Hemothorax, or blood in the pleural space, is caused by injuries to lung parenchyma, ribs, muscles, and vessels in the thoracic cavity and the chest wall. Patients may present with massive hemothorax if injuries to vascular structures are sustained. The treatment of choice for any size hemothorax is tube thoracostomy. The majority of hemothoraces are adequately drained by the initial tube thoracostomy without the need for further surgical intervention. Approximately 20% of patients with a hemothorax may have a retained hemothorax that was not adequately drained by the initial tube thoracostomy placement. A retained hemothorax is defined as persistent heterogenous fluid collection within 14 days of initial tube thoracostomy placement requiring a secondary intervention. Secondary interventions may include, placement of another tube thoracostomy, operative interventions, such as Video-Assisted Thoracoscopic Surgery (VATS), open decortication or intrapleural thrombolysis utilizing urokinase or tissue plasminogen activator. Inadequately drained hemothoraces or retained hemothoraces lead to high rates of fibrothorax, pneumonia, or empyema [1]. Therefore, drainage of hemothoraces in trauma patients is essential to prevent mortality and further morbidity. The size of the tube thoracostomy for initial drainage or as a secondary

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intervention is not well elucidated. Currently, there are no guidelines or consensus statements for the size of tube thoracostomy placement. We reviewed the current literature to evaluate the efficacy of small- and large-bore chest tubes to adequately evacuate a hemothorax during the initial placement or for a retained hemothorax.

Search Strategy

An electronic search of PubMed was conducted. Several combinations of the following search terms were utilized: traumatic hemothorax, management of traumatic hemothorax, tube thoracostomy for traumatic hemothorax, chest tube for hemothorax. Articles published in the English language are utilized.

In accordance with GRADE methodology, we formulated Population (P), Intervention (I), Comparator ©, and Outcome (O) questions (Fig. 26.1).

Results

Hemothoraces

Although most blunt chest trauma may be managed by nonoperative methods, penetrating trauma carries a higher mortality rate. The trajectory of missiles and their associated injuries leads to an emergent demand for operative intervention for life-threatening hemorrhage. All trauma patients should be managed to utilizing Advanced Trauma Life Support (ATLS) guidelines [2]. During the primary survey any life-threatening massive hemothorax must be identified. Adjuncts to the primary survey such as upright plain radiograph of chest or extended Focused Assessment with Sonography for Trauma (eFAST) should be utilized to identify hemothorax. A plain chest radiograph may identify a hemothorax volume of 500 cc. Smaller volumes of blood may be identified with Computed Tomography (CT) of chest after secondary survey is completed. Thoracic ultrasound also aids in diagnosis of hemothorax and is more sensitive for hemothorax than a plain radiograph of the chest. Massive hemothorax leads to life-threatening tension hemothorax, which must be evacuated emergently. Tube thoracostomy placement with drainage of greater 1500 cc in a 24-h period or drainage of greater than 200–400 cc of blood per hour prompts for emergent thoracotomy for exploration hemorrhage control.

Patients	Intervention	Comparator	Outcomes
Insertion of chest tubes	Small bore chest tubes, large bore chest tubes, pigtail catheters	Flow rates, evacuation of hemothoraces	Retained hemothoraces, morbidity

Fig. 26.1 PICO table

Management

ATLS guidelines recommend insertion of 28–32Fr chest tube in the fourth or fifth intercostal space in the anterior axillary line [2]. Tube thoracostomy is the most common method of management of a large or small hemothorax. A tube thoracostomy is measured in French or Charrière (Fr or Ch). One Fr is equivalent to 0.333 mm and is measured at the outer diameter of the tube. The use of large-bore (32–46Fr) or small-bore (14–22Fr) tube thoracostomies are debated and based on physics described by Poiseuille's law (Fig. 26.2). The law describes that flow of fluids (Q) is related to a number of factors including the viscosity of fluid (n), pressure gradient across the tubing (P), and the length (L) and diameter (r) of the tubing. A small increase in tube diameter will theoretically increase flow. Therefore, larger bore tubes are used in emergent settings. The viscosity of the fluid affects flow. An acute hemothorax consists lower viscosity blood and may be amenable for drainage with small- or large-bore tube thoracostomies. As blood accumulates in the pleural cavity, the diaphragmatic and chest wall motion leads to defibrination of blood, which leads to incomplete clotting. This phase of hemothorax may also be amenable to either small- or large-bore tube thoracostomy drainage. Within a few hours of cessation of bleeding, pleural enzymes may cause clot lysis. However, if there is massive hemothorax, clot lysis is incomplete and will lead to retained hemothorax. The viscosity of clotted blood is not amenable to tube thoracostomy drainage of any size. Small pigtail catheters were introduced for pleural pathology management of pediatric patients [3, 4]. Subsequent studies were performed comparing pigtails or small-bore catheters to large-bore catheters in hemothorax management. Insertion of a pigtail is commonly performed by radiologists and is less invasive. Ultrasound guidance can be utilized for precise localization in insertion of a pigtail catheter.

In an experimental study performed to assess the drainage capacity of 19F and 28F silicone drains, an increased rate of flow was found in the larger bore drain in the in vitro study [5]. However, when studied in vivo, there were no differences in the drainage capacity between the two drain sizes over time. In an in vitro study examining the flow of viscous bodily fluids, larger bore catheters were found to provide more rapid drainage [6]. A swine model study performed demonstrated more rapid blood drainage from a chest tube versus a pigtail catheter with no statistical difference [7]. The authors also measured total blood drainage which was higher in the chest tube group than the pigtail catheter group without statistical significance. A retrospective study by Tanizaki et al. comparing small-bore (20–22Fr) and large-bore (28Fr) tube thoracostomy demonstrated no differences in tube-related outcomes such as retained hemothorax, empyema, or need for additional tubes when placed in emergent settings [8]. In a prospective study performed by Inaba et al. comparing small-bore (28–32Fr) and large-bore (36–40Fr) tube

$$Q = \frac{\pi P r^4}{8 \eta l} \qquad Q = \frac{\pi P r^4}{8 \eta l}$$

Fig. 26.2 Equation for Poiseuille's law

thoracostomies for hemothorax, chest tube size did not impact pneumonia (4.9 vs. 4.6%; adj. $p = 0.282$), empyema (4.2 vs. 4.6%; adj. $p = 0.766$), or retained hemothorax (11.8 vs. 10.7%; adj. $p = 0.981$) [9]. However, the authors acknowledged larger bore tubes were used more frequently in patients with more severe injuries. In a prospective study performed by Kulvatunyou et al. comparing 14Fr pigtail catheters to larger bore tube thoracostomies (32–40Fr) in the management of hemothoraces, no differences in drain output or tube duration were observed [10].

Pigtail Catheters

In a prospective study performed by Kulvatunyou et al. comparing 14Fr pigtail catheters to larger bore tube thoracostomies (32–40Fr) in the management of hemothoraces, no differences in drain output or tube duration were observed [10]. However, pigtail catheters were more frequently used in patients with blunt injuries and were placed later when compared to patients who received larger bore tube thoracostomies. Bauman et al. published a larger study comparing pigtail catheters to larger bore tube thoracostomies and described a 7-year experience in their level 1 trauma center. During the 7-year period patients who received pigtail catheters were older (52 ± 21 vs. 42 ± 19, $p < 0.001$) and demonstrated a significantly higher occurrence of blunt trauma (86 vs. 55%, $p \leq 0.001$) [11]. The overall drainage from a pigtail was significantly higher (425 mL [IQR 200–800 mL] vs. 300 mL [IQR 150–500], $p < 0.001$). The authors concluded that pigtail catheters had similar outcomes to tube thoracostomy in terms of failure rates and tube insertion-related complications, and that the initial drainage output from Pigtail catheters was not inferior to that of tube thoracostomy.

Retained Hemothorax

Tube thoracostomy failure of complete hemothorax drainage may lead to retained hemothorax requiring secondary interventions. DuBose et al. stated that lower initial output (<300 mL) and pneumothorax as an indication for tube insertion may predict that patients will likely not need a second intervention. However, the size of tube thoracostomy was not cited as a factor [1].

When studying tube thoracostomy complications, it can be divided into insertional, positional, removal, infective, and equipment related [12]. A retrospective multi-institutional study comparing complications of small-bore tubes to larger bore tubes demonstrated the risks of having at least one chest tube complication was similar for both sized chest tubes (14 vs. 18%, $p = 0.42$) [13]. The authors demonstrated larger bore tubes had significantly larger risk of VATS, while small-bore tubes had significantly higher risk of pneumonia. Small-bore tubes also had lower initial output drainage rates compared to large-bore tubes (52.2 vs. 213.4 mL/h, $p < 0.001$) but had similar output volumes (738.0 mL vs. 810.9, $p = 0.59$).

Recommendation Based on the Data

Studies have demonstrated that drainage of hemothorax in the early phase of hemothorax may be amenable to small-bore thoracostomy or pigtail catheter placement. It may seem pain tolerance may improve with smaller-sized tube thoracostomies. However, the study performed by Inaba et al. did not see a difference in pain score using a visual analog [9]. In placing smaller bore chest tubes or pigtail catheters, initial technical skills in insertion can affect complications. Studies have demonstrated initial insertion-related complications of 5–8% [10]. Although there are no large prospective randomized trials or significant data to demonstrate its validity, large-bore chest tubes are frequently used in setting of hemothoraces in the emergent setting. Small-bore chest tubes may be considered in management of non-emergent settings. Ideal size of tube thoracostomy use in the management of hemothorax is left up to the discretion of the practicing surgeon and the clinical acuity of the patient.

Summary of Recommendations

- Small-bore (20–22Fr) and large-bore (28Fr) tube thoracostomy demonstrated no differences in tube-related outcomes such as retained hemothorax, empyema, or need for additional tubes when placed in emergent settings (evidence quality low; moderate recommendation).
- Comparing small-bore (28–32Fr) and large-bore (36–40Fr) tube thoracostomies for hemothorax, chest tube size did not impact pneumonia, empyema, or retained hemothorax (evidence quality moderate and moderate recommendation).
- Small-bore chest tubes may be considered in the management of non-emergent settings. Ideal size of tube thoracostomy use in management of hemothorax is left up to the discretion of the practicing surgeon and the clinical acuity of the patient (evidence quality moderate; strong recommendation).

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Tissue Plasminogen Activator (tPA) for Post-traumatic Retained Hemothorax

27

Fletcher K. J. Evans and David C. Evans

Introduction

Post-traumatic retained hemothorax (PTRH) is a common condition associated with chest trauma that, while generally manageable, leads occasionally to serious preventable complications such as empyema and fibrothorax with lung entrapment and chronic atelectasis. Current treatment approaches are inconsistent because of variability around key decision making regarding (1) when to undertake initial tube drainage of a presenting hemothorax; (2) what defines a clinically significant residual hemothorax requiring further intervention beyond tube thoracostomy; (3) and when and how to intervene when management is required. Therapeutic options in this latter instance include a combination of intrapleural fibrinolytic therapy (IPFT), video-assisted thoracoscopic surgery (VATS) and open thoracotomy, all variably applied in common practice. Because of its appealing biological rationale, ease of use, and common application in the management of empyema and complicated parapneumonic effusion, IPFT has gained acceptance as a recognized treatment for retained hemothorax [1]. The true benefit of IPFT for this indication in the setting of chest trauma is, however, unclear. While there exists potential benefit in the early evacuation of PTRH thereby obviating the need for subsequent surgical intervention, the possibility of harm due to provoked bleeding when used in patients with serious chest trauma is a reasonable concern. This chapter undertakes to evaluate current evidence informing the treatment of PTRH with IPFT.

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Search Strategy

In order to identify relevant scientific literature, PUBMED was interrogated employing the terms ((trauma[Title/Abstract] OR traumatic[Title/Abstract]) AND (lytic[Title/Abstract] OR fibrinolytic[Title/Abstract] OR fibrinolysis[Title/Abstract] OR TPA[Title/Abstract] OR tissue plasminogen activator[Title/Abstract] OR urokinase[Title/Abstract] OR streptokinase[Title/Abstract])) AND (hemothorax [Title/Abstract] OR pleural effusion[Title/Abstract] OR empyema[Title/Abstract] OR parapneumonic effusion[Title/Abstract]). Forty-eight articles were identified. All abstracts and full articles if required were reviewed to select observational studies evaluating intrapleural fibrinolytic therapy (IPFT) for retained hemothorax, as well as review articles and clinical guidelines addressing retained hemothorax. A reference search of these identified 19 articles was conducted to find an additional 56 articles of interest. All articles were then evaluated to select observational clinical studies evaluating defined outcomes of IFT using tPA in study populations that clearly described outcomes in patients with PTRH. Studies evaluating only non-trauma-related pleural collections or the use of SK or UK, but not tPA, were excluded.

Results

The specific question addressed is whether or not IPFT with tPA is safe and effective in the treatment of PTRH. Table 27.1 presents the question in PICO format specifying the outcomes of interest. Successful treatment should primarily reduce the incidence of empyema or lung entrapment, and obviate the need for related procedural interventions (image-guided chest drainage, VATS, or thoracotomy/decortication) without causing undue harm (provoked bleeding, transfusion, increased length of stay, and death).

Because trauma patients with retained hemothorax at a highest risk of serious re-bleeding with IPFT due to associated acute pulmonary and chest wall injury, it is important that they be evaluated as a distinct group. Key outcomes should capture

Table 27.1 PICO search strategy framework

Study parameter	Specification
P (Patients)	Patients with retained hemothorax due to blunt and penetrating chest trauma
I (Intervention)	Intrapleural fibrinolytic therapy (IPFT) with tissue plasminogen activator (tPA) via tube thoracostomy
C (Comparator)	Tube thoracostomy without intrapleural thrombolytic therapy
O (Outcomes)	• Surgical intervention (VATS, open thoracotomy, decortication) • Positive clinical effect (radiologic improvement, clinical assessment) • Empyema • Hospital length of stay • Post-tPA pleural hemorrhage • Mortality

both benefit and safety. If safe and effective in multiple trauma patients, IPFT could reasonably be assumed to be useful in post-surgical and medical patients with retained hemothorax due to other causes.

Any practical evaluation of IPF must consider the natural history of PTRH. In A 10-year single center retrospective study by MacLeod et al. evaluating 522 adult patients with hemothorax due largely to penetrating injury found that PTRH developed in one-fifth (21%) [2]. While the overall empyema rate was only 4% (presumably due to retained hemothorax) and generally managed with tube thoracostomy augmented by surgical decortication and/or intrapleural streptokinase, PTRH patients remained more than 2 weeks longer in hospital.

In a subsequent 2-year multicenter observational trial conducted by the American Association for the Surgery of Trauma (AAST), DuBose et al. evaluated outcomes of PTRH in 328 patients who had received chest tubes within 24 h of admission at 20 U.S. centers [3]. A major finding was that pneumonia and empyema complicated recovery in 1.9% and 26.8% of patients, respectively. While video-assisted thoracoscopy was the initial management in one-third of PTRH patients (more than two-thirds requiring two or more VATS procedures), 20% of all patients ultimately underwent open thoracotomy.

Interesting about the AAST study was the very limited use of IPFT for retained hemothorax. Fewer than 5% of all patients with PTRH received IFT as first-line management, and only occasionally was it used as second-line management after VATS or thoracotomy. As this study constitutes the largest prospective evaluation of PTRH patients yet published, it is meaningful that the role of IPF could not be more clearly elucidated.

Preliminary Evidence for Intrapleural Fibrinolytic Therapy

Research evaluating IPFT in general is confounded by both the range of clinical indications for its use, and the therapeutic regimens employed. While many studies have evaluated IPFT for the treatment of complex pulmonary effusions (CPE), a spectrum of predominantly infectious or inflammatory conditions such as loculated effusion and empyema are generally the focus. Intrapleural hemorrhage from a variety of causes is often included, but variably so, making interpretation of results specific to retained hemothorax difficult, particularly in the setting of trauma. In studies focusing more explicitly on retained hemothorax, the use of chest drains, image-guided percutaneous drainage, VATS, and open thoracotomy as therapeutic co-interventions render conclusions from these generally retrospectively assessed single-institution studies challenging to apply in daily practice.

Finally, a multitude of earlier IPFT studies treated patients with streptokinase (SK) [4–6], urokinase (UK) [7], or a combination of SK, UK, and recombinant tissue plasminogen activator (tPA) [8–10]. Both SK and UK have been supplanted in the U.S. by tPA in recent years and are no longer available. Streptokinase was found to be antigenic in patients and urokinase, used as an alternative, posed safety concerns of viral transmission related to its manufacture. While more current studies

specifically evaluate tPA, dose, concentration, timing, frequency, and duration are highly variable.

For clarity and simplicity, this discussion focuses solely on the use of tPA for retained hemothorax in the setting of blunt or penetrating chest trauma. In the absence of stronger evidence, recommendations could reasonably be applied to the management of hemothoraces arising in other circumstances.

There are two recent systematic reviews examining IPFT for PTRH. The first, completed in 2018, identified ten trials reported between 1996 and 2016, only three of which evaluated the use of tPA specifically. Of the combined 1308 patients reported upon, only 162 (12%) had PTRH, and of these, only 39 (3%) were treated with tPA [11]. The second review by Holson et al. completed in 2019 examined 63 patients assembled from six trials published between 2004 and 2017 [12]. One of the trials, contributing one-third of patients, actually used both tPA and SK without clear distinction, and two studies did not specify whether hemothoraces were due to trauma or other causes [13–15]. While both reviews reported greater than 80% effectiveness of IPFT for PTRH, one recommended that the use of higher doses and volumes of tPA be considered, while the other called for controlled trials. The accumulated evidence for safety and effectiveness was promising but weak due to very few patients studied and extensive confounding.

Results

Seven peer-reviewed observational studies evaluated tPA for the treatment of retained hemothoraces in trauma patients who were clearly specified in the published reports [16–21]. Four studies evaluated trauma patients exclusively, while three reported on trauma patients within a mixed population with varying pleural conditions (Table 27.2). All were single-institution studies without control groups that contained from 6 to 24 trauma patients (99 total) treated with a variety of tPA dosing regimens. Using the GRADE framework for evaluating quality of evidence, Guyatt et al. concluded that the evidence generated by these studies was considered very low quality in all cases [22].

Pooled analysis of study results is not useful due to study heterogeneity and small subject numbers. The findings are nonetheless instructive. Successful use of tPA was documented in 71% (70/99) of patients with 49% (48/99) undergoing subsequent surgical procedure (VATS or thoracotomy/decortication). An obvious discrepancy exists in the incidence of subsequent surgery exceeding the reported number of successes. Empyema as a particularly serious consequence of inadequately managed PTRH was only mentioned as an outcome of interest in two of the studies (4 of 26 patients). All studies reported the occurrence of post IPFT bleeding where a cumulative incidence of only 2% was counted. The mean hospital length of stay captured in two studies was approximately 20 days, and no deaths attributable to PTRH occurred in any study. With the low mortality rate noted, it is concerning that deaths associated with IPFT have been reported. The author is directly aware of

Table 27.2 Summary of findings from key observational studies evaluating intrapleural fibrinolytic therapy with tPA in the treatment of PTRH

Study identification							
Author	Skeete	Ben-Or	Stiles	Caylor	Heimes	Mangan	Narsule
Publication year	2004	2011	2014	2014	2017	2020	2017
Study quality							
GRADE assessment	Very low ⊕	Very low ⊕	Very low ⊕	Very low ⊕	Very low ⊕	Very low ⊕	Very low ⊕
Study details							
Enrollment period	1999–2993	2004–2009	2009–2011	2020–2013	2007–2012	2016–2018	40 months
Observation study design	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Control group	No	No	No	No	No	No	No
Institutions involved	Single	Single	Single	Single	Single	Single	Single
Subjects	Mixed	Mixed	Trauma	Trauma	Mixed	Trauma	Trauma
Enrolled (all subjects)	41	118	7	24	103	15	14
Enrolled (trauma)	6	13	7	24	20	15	14
IPFT agent	tPA	tPA	tPA	tPA	tPA	tPA	tPA
tPA does (total median)	2–50 mg	25 mg/120 mL NS	(24 mg)	10–50 mg	6 mg/50 mL NS	24 mg	(28 mg)
Number of doses	1–3 doses	1–8 doses	1–5 doses	Once daily	Once daily	Once daily	1–6 doses
Dosing interval	Unspecified	Unspecified	Unspecified	3 days	3 days	3 days	Unspecified
Time to dosing (days)	22 days (max)	Unspecified	Unspecified	Unspecified	12.8 days (1–32 days)	5 days (median)	5.5 days
Study outcomes							
Positive clinical effect	5/6 (83%)	8/13 (61.5%)	7/7 (100%)	14/24 (58.3%)	15/20 (75%)	14/15 (93%)	7/14 (50%)
Post-IPT ssurgery	16.6% (1/6)	4/14 (30.8%)	1/7 (14%)	20/24 (83.4%)	5/20 (25%)	10/15 (67%)	7/14 (50%)
Empyema	16.6% (1/6)	Unspecified	Unspecified	Unspecified	3/20 (15)	Unspecified	Unspecified
Post-IPT bleeding	0/6 (0%)	0/13 (0%)	0/7 (0%)	0/24 (0%)	0/20 (0%)	1/15 (7%)	1/14 (7%)
Hospital length of stay	Unspecified	Unspecified	14 days (5–23)	Unspecified	22 days	Unspecified	Unspecified
Mortality (attributable)	0/6 (0%)	Unspecified	0/7 (0%)	Unspecified	3/20 (15%)	Unspecified	0/14 (0%)

one fatality related to the use of tPA for PTRH in a patient receiving systemic anticoagulation for pulmonary embolism in an unmonitored unit.

The most striking findings of the evidence reviewed was extensive variability in the dosing of intrapleural tPA, and the variability in time to initiating IPFT following admission. Doses ranged from 2 to 50 mg. Some series cited once daily instillation of tPA repeated over several days, while others described the administration of several doses repeated within a single day.

Recommendations Based on the Data

Authoritative practice guidelines reviewing a broad range of evidence on the management of hemothorax were published by the Eastern Association for the Surgery of Trauma in 2011 These make weak (level 3) recommendations that traumatic hemothoraces of any size should be drained by tube thoracostomy and strong recommendations that subsequent retained hemothoraces should be managed by early VATS (level 1), advising intervention in the first 3–7 days of hospitalization (level 2). A weak recommendation is made to consider IPFT for loculated or exudative collections later in the clinical evolution, ostensibly following VATS in the second week post-injury. The recommendation that VATS is preferred to IPFT as first-line treatment for PTRH was based largely on the finding of a shorter mean hospital stay in a single-institution retrospective review comparing outcomes in 65 patients with PTRH treated initially with VATS or intrapleural SK over a 10-year period [23].

While it is possible that early VATS may be the most effective management strategy for PTRH with IPFT as second-line treatment, the strong possibility exists that the reverse may be preferred. Namely, early aggressive use of IPFT may resolve a majority of retained hemothoraces following chest tube insertion for significant traumatic hemothoraces, obviating the need for other interventions entirely. Salvage with VATS promptly after failed IPFT would potentially resolve the majority of residual hemothoraces, and the need for thoracotomy and decortication might become far less common than the 20% demonstrated in the AAST multicenter study. Management strategies must be evaluated as bundled approaches to care protocolizing decision making about everything from the indication for initial chest tube insertion to the timing and indication for thoracotomy and decortication. Interesting data suggests that maneuvers as simple as patient positioning and saline irrigation of the pleural space following chest tube insertion may prevent PRTH [24].

It is not possible to advocate strongly for the use of intrapleural tPA for posttraumatic retained hemothorax based on the very low quality of evidence made available in seven heterogeneous uncontrolled observational studies evaluating fewer than 100 patients combined. With none currently registered, one or more well-designed controlled prospective trials are still needed to prove efficacy and, more importantly, safety. Any future trial must offer clear definitions of retained hemothorax, successful management and important complications such as bleeding, empyema, and entrapped lung. Moreover, co-interventions such as thoracostomy

drain use, image-guided drainage, VATS, and thoracotomy must be bundled into a care pathway that also incorporates an unambiguous dosing regimen for tPA.

- It is not possible to advocate strongly for the use of intrapleural tPA for post-traumatic retained hemothorax based on the very low quality of evidence made available in seven heterogeneous uncontrolled observational studies evaluating fewer than 100 patients combined (evidence quality low; no recommendation can be made).

Personal View of the Data

Given the seemingly low risk of serious complications if administered safely, it seems logical to attempt IPFT evacuation of PTRH with intrapleural tPA as soon as possible after the diagnosis is made in order to try and avoid VATS. If surveillance chest X-ray in the stabilized patient suggests the presence of retained hemothorax more than 24 h after chest tube insertion, a CT chest is obtained to confirm the presence of a significant retained hemothorax. If present, we then administer 6 mg tPA in 100 mL NS per chest tube 2–3 times at 4-h intervals with patient positioning to favor admixture of the tPA solution and clotted intrapleural blood. We ensure careful clinical surveillance of patients during treatment, but do not mandate monitoring in a high acuity unit unless anticoagulated. Although the half-life of tPA in circulation is approximately 5 min, it is not absorbed from the chest cavity and there is always plausible concern for provoked bleeding at the site of injury which must be observed for. If there has been no clear effect of tPA as gauged by self-limited sanguinous chest tube drainage and improvement on chest X-ray, we proceed to VATS as expeditiously as feasible, normally within 3–5 days post admission. Interestingly, increased enthusiasm for early rib fixation for flail chest wall injury at our institution is obviating the need for retained hemothorax management in an important subgroup of patients.

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Rib Plating in the Acute Trauma Setting

28

James Dahm and Jason Strelzow

Introduction

The indications and methods employed in the fixation of multiple rib fractures have evolved significantly since Judet's description of metal strut fixation in 1973 [1]. Despite the publication of a number of randomized controlled trials (RCTs), systematic reviews, and meta-analyses, the optimal treatment of trauma patients with rib fractures and flail chest remains controversial. To date, there have been six published randomized controlled trials that compare various outcomes of patients with rib fractures treated with surgical stabilization of vs. supportive ventilatory care [2–7]. These studies were conducted in Egypt, Australia, the United States, China, and Japan and are relatively small, encompassing a total of 282 patients between the operative and nonoperative groups. They were, therefore, underpowered to detect differences in mortality between the two treatment options and may not apply directly to the North American system of trauma care, but they did contribute to our knowledge of surgery's effects on duration of mechanical ventilation, ICU and hospital stay, and incidence of pneumonia. Additional systematic reviews, meta-analyses, and retrospective studies largely draw similar conclusions. In this chapter, we summarize the findings of RCTs in addition to 11 systematic reviews and propose evidence-based indications for surgical stabilization of flail chest in the acute trauma setting.

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Search Strategy

We used the following search terms to query PubMed for clinical trials, systematic reviews, or meta-analyses published after 2000 (Table 28.1).

((("2000"[PDAT]: "2020"[PDAT])) AND (("controlled clinical trial"[Publication Type] OR "meta-analysis"[Publication Type] OR "randomized controlled trial"[Publication Type] OR "systematic review"[Publication Type] OR "pragmatic clinical trial"[Publication Type] OR "controlled clinical trial"[Publication Type])) AND (plating OR plate OR fixation OR orif OR surgery) AND (((rib OR chest) AND fracture) OR flail chest)

This search yielded 57 results. 38 were excluded for irrelevance to the present topic. Two randomized controlled trials [2, 7] and two prospective cohort trials were manually added from the reference list of the included systematic reviews, resulting in a total of 22 articles reviewed. Sixteen of these articles were classified as systematic reviews/meta-analyses [8–22] and six were randomized controlled trials [2–7]. One randomized controlled trial did not report data important to its analysis (for example, the number of patients randomized to each group) and utilized questionable exclusion criteria (women were excluded from the analysis due to "gender differences in pain tolerance") and was therefore excluded from consideration in this chapter [7]. The remaining 16 systematic reviews/meta-analyses and five RCTs were utilized as the basis for the recommendations in this chapter.

Results

Study Designs

Randomized Trials

Overall 282 patients were included in five randomized controlled trials [2–6]. The included studies were predominantly performed on flail chest patients, defined consistently throughout the literature as at least three consecutive, segmental rib fractures, with the exception of the Pieracci et al. RCT which only evaluated non-flail fracture patterns [5]. All of the included RCTs excluded patients under 18 years of age, those with significant traumatic brain injuries, and "significant associated trauma" which was ill-defined. The percentage of intubated patients was also variable between trials further complicating comparison, with some trials not reporting the percentages of intubated patients while other trials only included 50% intubated

Table 28.1 PICO table

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with acute rib fractures	Open reduction and internal plate fixation of acute rib fractures	Nonoperative management	Mortality, ventilator-days, ICU stay, hospital stay, incidence of pneumonia, tracheostomy rate, cost effectiveness

patients. Finally, each trial used various fixation methods without a standardized treatment approach. Included techniques ranged from Judet Strut rib fixation[6], bioabsorbable plates [4], traditional fracture wires [2], U-Plate [3], and commercial plates [5]. Overall outcome measures and reported complications varied between trials (Table 28.2).

Systematic Reviews

Sixteen systematic reviews were available for review. The majority of these reviews included flail chest segments as their primary focus while three included either single or multiple segment fractures [11, 12, 22]. Of these systematic reviews only three evaluated randomized trial data alone [9, 10, 19]. In all, these reviews spanned 46 unique patient cohorts and studies. Outcomes varied across these available studies however, all reported complications. Study designs varied from case reports and series to non-randomized and randomized trials for inclusion.

Outcomes

Mortality

Three of the five well-conducted randomized controlled trials reported in-hospital mortality rates among patient cohorts. None of the RCTs were powered for mortality by design, and all failed to show a statistical difference in mortality. In the Granetzny study, two of twenty patients in the operative group and three of twenty in the nonoperative group died during hospitalization. One of 23 in the nonoperative group and none of the 23 patients in the operative group died in the hospital in the Marasco study. Similarly, the Liu et al. study found four of 25 in the surgical group (16%) and two of 25 in the nonoperative group (8%) died in hospital. The majority of the retrospective and non-randomized trails reviewed in the meta-analysis reported mortality data (40 of 46) with an overall mortality risk of 2.9% [17]. Overall the systematic reviews reported significantly fewer mortalities in the groups that underwent surgical fixation, with a number needed to treat of 5 in one [20]. This difference, however, was only borne out in prospective cohort studies and retrospective reviews. Thus, the effect of SSFC on mortality at this time remains unclear, but there may be a mortality benefit to surgical stabilization of flail chest injuries that has yet to be demonstrated in larger controlled studies.

Duration of Mechanical Ventilation

Pooled analysis of mechanical ventilatory time is difficult due to substantial variation in the reporting methods and outcomes. Overall, surgical stabilization of flail chest appears to consistently demonstrate reduced duration of mechanical ventilation compared with supportive management. Surgical stabilization in the non-flail chest does not appear to provide an advantage in time to wean from ventilatory support [5]. The Granetzny and Tanaka RCTs both demonstrated significantly fewer ventilator-days (an average 10 fewer in the Granetzny study and 7.5 fewer in the Tanaka study). No difference was found in the Marasco RCT;

Table 28.2 Summary of randomized controlled trial outcomes

	Year	Indication	Intervention	Patients	Timing of surgery	Deaths	Incidence of pneumonia	Hospital stay (days)	ICU stay (days)	Ventilator days	Tracheostomy	Chest wall deformity
Tanaka	2002	Flail chest	Judet strut fixation	18	Within 5 days of injury	NR	**4 (22%)**	NR	**16.5**	**10.8**	**3 (17%)**	NR
			"Internal pneumatic stabilization"	19		NR	**17 (90%)**	NR	**26.8**	**18.3**	**15 (79%)**	NR
Granetzky	2005	Flail chest	Wire fixation	20	Within 24–36 h of ICU admission	2	**2 (10%)**	**11.7**	**9.6**	**2**	NR	**1 (5%)**
			Adhesive plaster for 7–10 days	20		3	**10 (50%)**	**23.1**	**14.6**	**12**	NR	**9 (45%)**
Marasco	2013	Flail chest	Bioabsorbable plates	23	Within 48 h of injury	0	11 (48%)	NR	**11.875**	NR	**9 (39%)**	1 (4%)
			"Best practice ventilator management"	23		1	17 (74%)	NR	**14.958**	NR	**16 (70%)**	1 (4%)

	Year	Indication	Intervention	Patients	Timing of surgery	Deaths	Incidence of pneumonia	Hospital stay (days)	ICU stay (days)	Ventilator days	Tracheostomy	Chest wall deformity
Liu	2019	Flail chest	U-plates	25	"As early as possible"	4	**12 (48%)**	21	**10**	**7**	10 (40%)	**2 (8%)**
			Pain control, chest splint/ bandage, chest PT	25		2	**20 (80%)**	22	**12**	**9**	7 (28%)	**9 (36%)**
Pieracci	2020	Three ipsilateral, displaced rib fractures without flail chest	SSRF at surgeon's discretion	51	Within 72 h of injury	0	NR	NR	NR	NR	NR	NR
			Standardized pain control regimen	59		0	NR	NR	NR	NR	NR	NR

Variables found to be statistically different are highlighted in bold

however, there was a trend toward fewer ventilator-days in the operative group, and extubated patients in the nonoperative group required longer durations of non-invasive ventilation. Similarly, all meta-analyses and retrospective reviews demonstrate shorter durations of mechanical ventilation with SSFC with average effect sizes between 4.52 and 7.5 days. The only exception is the Cochrane Review, in which the authors considered it inappropriate to combine the RCTs due to a wide range of ventilation durations and lack of clarity on intubation reporting [9]. Therefore, the data appear to demonstrate a potential improvement in time to ventilatory wean for those patients with flail chest treated with surgical fixation compared with supportive management however, there remains limited level 1 and 2 scientific data to support this. Consistent reporting and protocols around the use of mechanical ventilation is required to further elucidate the effect of rib fixation on mechanical ventilation duration.

Length of Intensive Care

Each of the four RCTs specifically evaluating patients with flail chest demonstrated significantly fewer days in the ICU for patients treated with rib stabilization compared with supportive care with a range of 3.1–12 days. Interestingly, Liu et al. sub analyzed their patient population for the presence of pulmonary contusions and found that when present, the length of ICU stay and mechanical ventilation was similar between conservative and surgical groups [3]. This suggests that overall injury severity may play a larger role than treatment modality for this patient population. The results of seven meta-analyses and systematic reviews were similar. Surgical fixation resulted in 2.3–6.5 fewer ICU days, all statistically significant. In addition to fewer days ventilated, flail chest patients who undergo rib fixation seem to spend fewer days in intensive care. Here again, substantial data heterogeneity limits firm conclusions as outlined by Cataneo et al. in their Cochrane Review [9]. Data on ICU admission varied considerably between trials; some reporting total ICU time and other reporting post-operative ICU duration. Overall, there appears to be a potential positive effect of surgical fixation of flail chest segments on length of ICU stay; however, definitive conclusions are not yet elucidated.

Length of Hospitalization

Only one RCT reported a significant reduction in hospital days in patients who underwent surgical fixation of flail chest injuries (11.7 days in the operative group vs. 23.1 in the nonoperative group) [2]. Marasco and Liu found no significance between the two groups, and Tanaka did not report length of hospital stay as an outcome. Systematic reviews and meta-analyses suggest a statistically significant decrease in hospital stay in those patients undergoing surgical rib fixation (seven systematic reviews/meta-analyses) with a mean between 3.8 and 11.4 days [9, 10, 13, 15, 19–21]. We conclude that surgical stabilization of rib fractures likely reduces hospital stay, though with slightly less confidence than its effects on duration of ventilation or length of ICU stay.

Incidence of Pneumonia/ARDS

Four trials reported rates of in-hospital pneumonia among flail chest patients. Three of the RCTs reported significantly fewer cases of pneumonia among their patients that underwent SSRF [2, 3, 6]. Tanaka et al. also assessed for pneumonia at two time points. Pneumonia rates were not significantly different at 7 days, but 90% of flail chest patients in the nonoperative group developed pneumonia at 21 days compared with 22% of the operative group. Marasco et al. found no significant difference in development of pneumonia but did report a protective trend following surgical fixation. Pieracci et al. found no difference in rates of ARDS or pneumonia in patients with non-flail chest fixation [5]. Each of the systematic reviews and meta-analyses found significantly fewer cases of pneumonia in the operative groups, with a difference ranging between 25 and 59%. The Cochrane Review reported a number needed to treat of two to prevent pneumonia [9]. These findings suggest robust evidence that SSFC may prevent the development of pneumonia during hospitalization.

Tracheostomy

The Marasco, Tanaka, and Liu randomized trials evaluated rates of tracheostomy, while the Granetzky and Pieracci trials did not. Marasco and Tanaka found much lower rates of need for tracheostomy in patients treated with surgical rib fixation (a difference of 62% at 21 days in the Tanaka study and an overall difference of 31% in the Marasco study), However, Liu et al. did not find a difference in their study despite the highest rates of intubated patients in their cohort (>75% of patients). Systematic reviews/meta-analyses corroborate these findings, with the Cochrane Review suggesting a number needed to treat of two to prevent tracheostomy [9, 15, 19, 21]. Based on conflicting data, and the low-level evidence assessed in the meta-analysis definitive conclusions from this data are difficult to draw. At this time, additional higher level of evidence is required to support or refute any effect of surgical fixation on rates of tracheostomy.

Cost Effectiveness

Only one RCT commented on the cost of care in the operative vs. nonoperative groups, finding that the total cost of care was significantly lower in the operative group ($13,455 ± $5840 vs. $23,423 ± $1380, $p < 0.05$) [6]. It should be noted that these costs were from episodes of care from 1992 to 1998 in Tokyo, and contemporary North American costs are likely significantly different. Two additional studies used decision-analysis models to estimate total costs of care of operative vs. nonoperative treatment of flail chest. Their decision models were similar, but Swart et al. estimated costs based on real-world variable costs obtained from trauma centers and a literature review, and Bhatnagar et al. used Medicare reimbursement rates for diagnoses and procedures [8, 21]. Both found SSFC to be cost-effective, with an incremental cost-effectiveness ratio of $8577 per quality-adjusted life year in the Swart et al. study.

Timing of Surgery

There have been no studies that specifically evaluate the timing of SSFC. Operative guidelines recommend fixation within 72 h to avoid the extra difficulty associated reducing fractures in the setting of early callus [23]. Ultimately, the timing of surgery for flail chest injuries will depend on the patient's state of extremis and concomitant injuries (e.g., unstable spine fractures that may limit positioning options prior to spinal stabilization).

Indications for Rib Fracture Fixation in Patients Without Flail Chest

Currently there is only one RCT evaluating the use of surgical fixation of rib fractures in the setting of non-flail chest injuries [5]. The study included 110 patients with at least three displaced, ipsilateral rib fractures without flail chest in a pseudo-randomized trial design with only 21% of patients electing to be randomized. The data from this trial suggests no differences were seen in hospital or ICU length of stay, length of mechanical ventilation, or pneumonia/ARDS between surgical and non-surgical treatment arms. There was, however, a noted statistically significant improvement in Numeric Pain Scores (2.9 vs. 4.5) at 2 weeks which persisted over the subsequent 4-week and 8-week follow-up periods. Overall, the improvements were modest, and there were no differences in quality of life scores between groups. In light of limited, high level evidence, any recommendation on the use of rib fracture fixation in non-flail chest patients is limited.

Recommendations Based on the Data

Based on the available evidence, we can reasonably conclude the following:

- Intubated adult patients with flail chest segments and paradoxical chest wall movement or failure to liberate from ventilation without significant traumatic brain injury and associated severe trauma should be considered for rib fraction fixation (Evidence quality moderate, moderate recommendation).
- Patients considered for rib fixation should undergo timely surgical intervention (<72 h) (Evidence quality low and based largely on expert opinion, weak recommendation).
- The gold-standard for fixation strategy and methods of fixation and ideal technique is unknown; therefore, any available method may provide similar results (Evidence quality very low, no recommendation).
- Non-intubated patients with respiratory decompensation despite maximum epidural, non-invasive ventilatory support and/or IV analgesic regimens in the setting of flail chest segments may be considered for fib fracture fixation (Evidence quality low, weak recommendation).
- Rib fracture fixation in patients without flail chest rib fracture segments may not provide improvement in hospital-based outcomes such as mortality or length of stay (Evidence quality moderate, moderate recommendation).

A Personal View of the Data

Based on the available literature and our clinical experience, we can reasonably conclude based on moderate-quality evidence or consensus among lower-quality studies that surgical fixation of intubated adults with flail chest injuries reduces overall cost of care, duration of mechanical ventilation, and incidence of pneumonia/ARDS with effect sizes that are clinically important. It should be kept in mind, however, that these conclusions are drawn from five relatively small RCTs, four prospective, non-randomized studies, retrospective reviews, and meta-analyses. It is additionally important to recognize that, while all the articles reviewed in this chapter studied patients with flail chest, the time to surgery, existence of paradoxical chest wall movement, and intubation status were either not reported or variable among studies. Additionally, rates of mechanical ventilation in the included patient populations varied as did outcome metrics. This generated significant heterogeneity in the available data limiting firm conclusions. Therefore, although there appears to be multiple clinical outcomes that potentially benefit from surgical stabilization of rib fractures, it is unclear exactly when and under which circumstances surgery should be performed. In addition, there is no evidence-based literature to recommend the approach, reduction strategy, choice of implant, or number of ribs that should be stabilized. Future studies should explore the comparative outcomes of surgically stabilized rib fractures compared to more up-to-date and standardized non-ventilatory strategies for the management of flail chest as well as novel modalities of pain control to prevent splinting and resultant intubation. Additionally, further analysis of implant choice (e.g., locking plates, Judet struts, intramedullary wires, bioabsorbable plates, 3D-printed plates) and its effect on outcomes is warranted. Larger well-conducted randomized controlled trials with standardized and specific inclusion criteria with similar results would lend confidence to the conclusions above. To our knowledge, there are at least two large randomized controlled trials on this topic currently underway which will shed additional light on these topics.

Based on the available literature and our clinical experience, we suggest surgical stabilization of rib fractures in the following scenarios:

1. Intubated patients with flail chest and paradoxical chest wall movement or failure to liberate from ventilation.
2. Non-intubated patients with respiratory decompensation secondary to displaced rib fractures/flail chest despite maximum epidural and/or IV analgesic regimens.
3. Patients with significant chest wall deformity or severely displaced fractures may that may puncture skin, pleura, lung and place the patient at risk for open fracture, pneumothorax, hemothorax, pulmonary herniation, or symptomatic malunion.

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29 Does Thoracic Irrigation at the Time of Chest Tube Placement Decrease the Incidence of a Retained Hemothorax?

Elliot S. Bishop and Louis R. Pizano

Introduction

Hemothorax (HTx) and hemopneumothorax (HPTx) are common problems following thoracic trauma. Tube thoracostomy (TT) is the initial intervention in the vast majority of cases [1]. Retained hemothorax (RH) remains a challenging sequelae to manage and can result in empyema, fibrothorax, and pneumonia which have been shown to increase length of stay, duration of ICU care, and mortality [2–4]. RH is not an uncommon problem, occurring in approximately 20% of trauma patients that receive TT for HTx and HPTx [5]. Many investigators have studied optimal treatment strategies and intervention timing for RH. Very few studies, however, have examined adjunctive procedures performed during initial TT in the prevention of RH. A technique that has gained interest in recent years involves irrigating the thoracic cavity with normal saline at the time of initial TT for traumatic HTx with the intention of minimizing the risk of subsequent RH. This has only been studied in a few small series. This chapter addresses the utility of thoracic irrigation at the time of chest tube placement and evaluates published literature on this topic.

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Search Strategy

Systematic methods were used to find relevant studies and evaluate their quality based on the established Patient, Intervention, Comparison, and Outcomes (PICO) questions (Table 29.1). We queried the PubMed, Google Scholar, and Cochrane Evidence Based Medicine databases for publications categorized with the terms "hemothorax," AND/OR "thoracic trauma," AND/OR "chest tube," AND/OR "tube thoracostomy," AND/OR "irrigation," AND/OR "retained hemothorax," AND/OR "hemothorax sequelae." Results were limited to those written in the English language, studying humans, and published within the last 15 years. Articles were hand screened for relevance and references were examined for additional works falling outside the search parameters. Articles primarily related to thoracic surgery and thoracic irrigation for non-traumatic etiology were excluded from analysis.

Results

Prior to addressing TT irrigation specifically, a brief overview of existing data on the topic of RH is helpful. Literature addressing the topic of RH reveals four broad areas of inquiry. The first group includes work done on the recognition and management of RH. These topics have been extensively researched and have informed standard of care practices for early VATS, intervention timing, and the use of fibrinolytics among others [1, 5–15]. Included in this group are studies that utilize thoracic irrigation at the time of surgical intervention for RH (VATS or thoracotomy). The second group includes published work examining a wide range of patient-related factors and injury features that predict the risk of RH. Initial TT output, injury severity, and bilateral injury are a few of the many factors that have been shown to increase the risk of RH [4, 16, 17]. The third group includes studies that evaluate variables involved in standard tube thoracostomy placement and their impact on the incidence of RH. Studies have examined chest tube size, chest tube position, and expertise or level of clinician performing TT with none of these providing data to change practice patterns or decrease the incidence of RH [16, 18, 19]. The final group, for which there is a paucity of data, includes research on adjunctive procedures performed during initial TT for HTx or HPTx with the intention of reducing the incidence of RH. Thoracic irrigation is one of the techniques that fall into this category and is discussed below.

Table 29.1 PICO table for chest tube irrigation at the time of placement

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with traumatic hemothorax	Chest tube irrigation at time of placement	Patients not receiving chest tube irrigation at time of placement	Morbidity (retained hemothorax, empyema), mortality, LOS, need for secondary intervention

Irrigation with Initial Tube Thoracostomy

There have been two studies (summarized in Table 29.2) that specifically evaluate the role of prophylactic thoracic irrigation at the time of TT placement in the prevention of RH. The first was a 2016 prospective observational trial of 20 patients by Kugler et al. [20]. In their protocol, a Yankauer suction catheter was used to clear the thoracic cavity prior to TT. One liter of warm normal saline was subsequently infused prior to connecting the chest tube to −20 cm suction. The primary measured endpoint was the need for secondary intervention including need for repeat TT, VATS, or thoracotomy due to RH or empyema. One patient of twenty required a secondary intervention. The authors concluded that the 75% reduction rate of secondary intervention (5% in their observational trial compared to a historic secondary intervention rate of 20%) may be attributed to the process of thoracic irrigation. The authors' proposed mechanisms for this improvement included the mechanical disruption of clotted blood and the greater distribution following dilution, allowing more blood evacuation through the chest tube.

Kugler's group followed this pilot study with a larger prospective comparative analysis in 2017 [21]. 296 patients were enrolled and divided into a non-irrigation control arm and a thoracic irrigation experimental arm. Sixty (20%) patients underwent thoracic irrigation at the time of initial TT placement. The irrigation protocol was identical to the pilot observational study discussed above. The primary measured endpoint was again the need for secondary intervention as defined by additional chest tube placement or operative management. They also measured secondary outcomes of TT duration, length of stay, ICU length of stay, and ventilator days. They found a statistically significant reduction in the need for secondary interventions (5.6 vs. 21.8%) but no difference in any of the secondary outcomes.

Table 29.2 Efficacy of chest tube irrigation at time of placement

Author (year)	*N*	Study type	Arms	Outcomes measured	*P* value
Kugler et al. 2016 [20]	20	Prospective observational	Standard TT placement (historic control) TT placement + suction evacuation + irrigation	Need for secondary intervention	N/A
Kugler et al. 2017 [21]	296	Prospective comparative	Standard TT placement TT placement + suction evacuation + irrigation	Secondary intervention (irrigated vs. non-irrigated)	<0.001
				TT duration	NS
				Length of stay	NS
				ICU length of stay	NS
				Days intubated	NS

Weaknesses in the two studies described above make it difficult to reach any definitive conclusions. Both studies are small with 20 patients in the 2016 study and 60 patients in the experimental arm of the 2017 study. The lack of randomization in both creates the possibility for selection bias. As acknowledged by the authors, patient factors and severity of injury may have affected which patients underwent irrigation. The use of suction evacuation prior to thoracic irrigation is a significant confounding variable. Suction evacuation prior to chest tube placement has only been investigated in two studies and the overall outcomes associated with this procedure are not fully understood [22–24]. It is difficult to determine the degree to which the results are due to suction evacuation versus the irrigation portion of the protocol. Finally, HTx size has repeatedly been shown to be a predictor of RH [16]. In the 2016 study, the initial HTx size/volume (200 cc) was only half the volume demonstrated by Villegas as the inflection point for an increased risk of RH [16]. The 2017 study does not list the initial output which further prevents the ability to definitively conclude that thoracic irrigation at the time of TT can reduce the risk of RH.

Recommendations Based on the Data

- For patients with traumatic HTx or HPTx, we recommend TT as the initial intervention for evacuating HTx (evidence quality high; strong recommendation).
- For patients with traumatic HTx or HPTx, there is insufficient published evidence at this time to support any recommendation either for or against the use of prophylactic irrigation at the time of TT to reduce the incidence of retained HTx and its sequelae (evidence quality low, recommendation moderate).

A Personal View on the Data

We recommend TT without irrigation as the initial management for HTX and HPTx. At the present time, thoracic irrigation with initial TT placement has only been studied in two small series. The larger of these demonstrated a statistically significant decreased rate of secondary interventions but no difference in length of stay, TT duration, ICU days, or ventilator days. Both studies were limited by lack of randomization, small sample size, and the flaws in experimental design discussed above. The perceived benefit of thoracic irrigation due to the dilutional effect of clotted blood prior to TT placement makes theoretic sense and it has been shown that thoracic irrigation can be performed quickly and without significantly increased risk to the patient. However, there is not enough evidence to recommend routine thoracic irrigation at the time of TT placement. Larger studies are still needed to demonstrate efficacy.

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The Timing of VATS for a Retained Hemothorax

30

Kaitlin A. Ritter, Jamie Coleman, and Mitchell Cohen

Introduction

In the era of modern laparoscopy and thoracoscopy, video-assisted thoracoscopic surgery (VATS) has increasingly become the standard of care for the management of retained post-traumatic pleural collections, including retained hemothoraces. A 2012 prospective observational trial from the American Associate for the Surgery of Trauma (AAST) found that approximately 1/3 of patients with retained hemothorax were initially treated with VATS [1]. This resulted in a 70% resolution of the hemothorax requiring no further interventions. This was in comparison to the 79% success rate of initial thoracotomy and only 36% success rate of a second tube thoracostomy suggesting similar to improved treatment efficacy of VATS as compared to historical standards [1]. Additionally, current Eastern Association for the Surgery of Trauma (EAST) practice management guidelines recommend after failed initial tube thoracostomy drainage, VATS should preferentially be performed for retained hemothoraces over the placement of a second tube thoracostomy [2].

While the adoption of VATS for the management of retained hemothorax has increasingly become of the standard of care, significant debate exists regarding the optimal timing of VATS in the post-traumatic setting. Several studies evaluating the efficacy of "early" VATS have utilized various time points as cut-offs for early vs. late intervention leading to significant debate [3–5]. In this review, we will explore

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the efficacy of early VATS at various time points and attempt to elucidate optimal timing for thoracoscopic intervention for retained hemothoraces.

Search Strategy

Investigators searched PubMed, the Cochrane Library, and Science Direct to identify relevant papers published between January 1990 and September 2020. The following search keywords were used: "VATS" OR "video-assisted thoracoscopic surgery" OR "thoracoscopy" OR "thoracoscopic" AND "hemothorax" OR "retained hemothorax" OR "residual hemothorax" OR "post-traumatic hemothorax." The search strategy limited papers to those published in English, full-text availability, and were limited to humans. RCT, cohorts, and case-control studies were included. Three evaluators independently assessed the search results for studies meeting inclusion/exclusion criteria from the assembled bibliography. Studies were eligible for inclusion if they compared outcomes of VATS over two-time points in retained post-traumatic hemothoraces. Studies were excluded if they only compared VATS to alternate treatment strategies, including tube thoracostomy and fibrinolytic therapy or evaluated only non-traumatic hemothoraces (i.e., post thoracic or cardiac surgery). Studies that examined VATS as primary management for traumatic hemothorax were also excluded (Table 30.1).

Results

Historically, significant variability had existed regarding the management of retained hemothoraces with a 2012 review of management strategies finding therapeutic interventions ranging from observation to repeat tube thoracostomy, thrombolytics, and surgical drainage via thoracoscopy or open approaches [1]. Despite these variations, a growing body of evidence exists supporting the early use of VATS, and thoracoscopic drainage. In a prospective randomized trial comparing second tube thoracostomy to VATS, patients who underwent surgical drainage had shorter durations of tube drainage, short hospital LOS, and shorter hospital costs. Additionally, authors found a high rate of failure of second tube thoracostomy (41.6%), with no failures noted in the VATS group [6]. These results support findings from several other retrospective cohort studies evaluating VATS vs. repeat tube thoracoscopy, intra-pleural streptokinase, and thoracotomy, which similarly

Table 30.1 Optimal timing of VATS for retained hemothorax PICO table

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Patients with retained hemothorax (trauma specific)	Early VATS	Delayed VATS	Procedural success PNA/empyema Vent time ICU and hospital LOS

demonstrated improved outcomes for patients undergoing thoracoscopic drainage [7–10]. The preponderance of data supporting the use of early VATS for drainage of retained hemothoraces is such that in 2011 the EAST practice management guidelines for management of hemothorax provided a level 1 recommendation for principle treatment of retained hemothoraces with VATS as opposed to second tube thoracostomy [2].

As VATS increasingly becomes standard of care in the treatment of retained hemothoraces, little consensus exists regarding optimal timing for such intervention. Several authors report the benefit of the early thoracoscopic intervention, but variability exists in the exact definition of early for these procedures. Some authors have reported interventions as soon as 2 days out from injury [7], while others have defined early intervention as within 10 days from injury [7, 11]. On the whole, most reviews of this topic report interventions within the first-week post-injury, but the differing methodologic time frames in each individual study and variable reported outcomes have made the determination of an optimal intervention time difficult.

Most studies cite a success rate, defined either as patients who did not require a second intervention after VATS or did not require conversion to thoracotomy at the time of hemothorax evacuation (Table 30.2). A retrospective review of 139 retained hemothoraces found.

a statistically significant improvement in VATS success (83.1%) when drainage was performed before day 5 as compared to 66.2% when delayed beyond day 5 [12]. These results are similar to those reported by DuBose et al. in their 2012 prospective observation multicenter AAST trial which found a 72% success rate for VATS performed after 5 days as compared to an 83% success rate for those intervened upon before 5 days. Interestingly, the authors did not identify any association between timing and procedural success despite analysis at various time points, including 1, 2, 3, 5, and 7 days [1]. This contrasts with a subsequent review of 136 patients with blunt chest trauma diagnosed with retained hemothoraces treated with VATS. The authors divided patients into three distinct time periods, finding patients intervened upon within 2–3 days of injury achieved a 98% success rate as compared to only 86% for interventions schedule 4–6 and greater than 7 days post-injury [3]. This significance of ultra-early VATS (within 3 days of injury) for procedural success is supported by a recent meta-analysis which found earlier thoracoscopic intervention (within 1–3 days) statistically favored a higher success rate [13].While variability exists in reported success rates, and no high-quality randomized controlled trials have been performed, based upon consistent trends in retrospective reviews, earlier drainage appears to be associated with easier surgical interventions and improved outcomes. This is supported by qualitative reports of increased intrathoracic adhesions, lung inflammation, and poor visualization due to pleural reaction for interventions performed at later stages [5, 11, 13]. Importantly, despite this variability in success rates, in evaluated studies, no time frame was associated with a significant difference in mortality with rates ranging from 0 to 5% [3, 12, 13].

With this relatively low mortality related to retained hemothoraces, the impetus behind the drainage of these collections is largely driven by the infectious and long-term pulmonary complications that result from residual blood in the pleural space. Empyema, pneumonia, and fibrothorax are all well-known complications occurring

Table 30.2 Outcomes of included studies

Study	Study type	Year	Timing of VATS (days)	No. of patients	Vent time (days)	ICU LOS (days)	Hospital LOS (days)	PNA/ empyema	Intervention failure	Mortality
DuBose	Prospective observational	2012	<5	64	–	–	–	–	17%	–
			>5	67	–	–	–	–	28%	–
Huang	Prospective observational	2018	<4	30	6.8*	8.9*	20.6*	33.3%/6.7%*	–	–
			>4	31	18.6*	17.7*	35.1*	51.6%/29.0%*	–	–
Lin	Retrospective cohort	2014	2–3	43	2.6	5.0	16.2	23%/11%	2%	0%
			4–6	57	6.8*	7.7*	21.3*	38%*/17%*	14%	2%
			>7	36	15.5*	14.6*	38.2*	64%*/39%*	14%	5%
Morales	Retrospective cohort	2008	<5	46	–	–	–	–	16.9%*	0%
			>5	93	–	–	–	–	33.8%*	0%
Vassiliu	Prospective observational	2001	<3	13	–	–	8*	–/7%*	–	–
			>3	11	–	–	12*	–/45%*	–	–
Ziapour	Meta-analysis	2020	1–3	106	–	–	–	–	8.5%*	0%
			4–6	181	–	–	–	–	11.0%	0.6%
			>7	189	–	–	–	–	32.8%*	1.1%

*Significantly different between two groups ($p < 0.05$)

LOS length of stay, *VATS* video-assisted thoracoscopic surgery, *PNA* pneumonia

at relatively high frequency [1, 13, 14]. Emphasis on prevention on these processes has focused on the early and complete evacuation of the pleural space. In correlation with the procedural success of early VATS, early drainage has also demonstrated statistically significant improvement in pneumonia and empyema rates in individual series. Authors have cited empyema rates ranging from 6.7 to 11% for early intervention (3–4 days from injury). This is in comparison to rates upwards of 29–45% for drainage after day 4 (Table 30.2) [3, 5, 15]. Interestingly, a large prospective multi-centered observational study from the AAST failed to find the correlation between pneumonia rates and timing of pleural drainage [16]. In the AAST review, of the 328 patients with retained hemothoraces, those who developed pneumonia were less likely to have undergone a VATS drainage, but there was no significant difference in risk of pneumonia if the VATS was performed before or after their 5-day cut off [16]. And while these findings are discordant with previous reports, the difference in examined time points may the driving factor behind these conflicting studies, with each of the retrospective studies finding the greatest impact of early VATS several days before the AAST's examined cut off.

In addition to the overall success and infectious outcomes of VATS interventions, other key metrics utilized to help guide optimal timing for drainage have included resource utilization such as ventilator time, ICU length of stay (LOS), and hospital LOS (Table 30.2). A prospective evaluation of utilization of early VATS for retained hemothoraces (<4 days) in patients with concomitant blunt head and chest injury found a statistically significant decrease in ventilator time by over half as compared to delayed drainage [15]. These findings are supported by a similar evaluation in blunt chest trauma, which likewise found a graded reduction in ventilator time with earlier intervention [3]. Both studies also evaluated ICU and hospital LOS, finding statistically significant decreases in both metrics with earlier intervention, with the best outcomes reported in patients with drainage procedures performed before 3 days [3, 15]. In a separate study, this improvement in hospital LOS with intervention before day 3 was also associated with a significant reduction in average hospital cost ($46,471) as compared to $126,221 for the delay intervention group [17].

Recommendations Based on the Data

To date, minimal high-quality data is available exploring the question of optimal timing for VATS in the setting of retained hemothoraces (Table 30.3). And while there is a lack of randomized controlled trials exploring this topic, data from moderate grade prospective and large retrospective series consistently demonstrate improved outcomes and procedural success associated with drainage procedures performed between 4 and 6 days.

With the advent of thoracoscopy and the growth of its utilization for various intrathoracic pathologies, including retained hemothoraces, prior treatment algorithms, which had relied upon second tube thoracostomy for management of retained hemothorax, have progressively gone by the wayside in favor of thoracoscopy. As data continues to support these minimally invasive interventions, questions

Table 30.3 Summary of included studies

Authors	Year	Reference title	Evidence quality	Study summary
DuBose et al.	2012	Management of post-traumatic retained hemothorax: A prospective, observational, multicenter AAST study. *J Trauma*. 2012;72(1):12–24.	Moderate	(n = 328) Multicenter prospective observational review of various approaches to retained hemothoraces and procedural success of each intervention. VATS arm included 131 patients. Found no significant time interval associated with increased success rate for VATS
Huang et al.	2018	Early management of retained hemothorax in blunt head and chest trauma. *World J Surg*. 2018;42:2061–2066.	Moderate	(n = 61) Single center prospective observational review of patients with concomitant blunt head and chest trauma. Designed to report safety of early VATS (<3 days) vs. delayed (>3 days) in patients with head injury. Demonstrated improved clinical outcomes including ICU/hospital LOS, infection rates and ventilator time in early intervention group
Lin et al.	2014	How early should VATS be performed for retained haemothorax in blunt chest trauma? *Injury*. 2014;45:1359–1364.	Moderate	(n = 136) Retrospective review of blunt chest trauma patients with retained hemothoraces divided into three intervention groups (2–3 days, 4–6 days, and >7 days). Found longer hospital/ICU LOS, vent times and higher pneumonia and empyema rates in latest intervention group. No difference between 2–3 day and 4–6 day groups
Morales et al.	2008	Best timing for thoracoscopic evacuation of retained post-traumatic hemothorax. *Surg Endosc*. 2008;22:91–95.	Moderate	(n = 109) Retrospective review of risk factors associated with VATS failure in chest trauma patients with retained hemothoraces. Found parietal and visceral pleural thickening associated with increased risk of failure. Measured various intervention time frames, inflection point for increased failure identified at >5 days
Vassiliu et al.	2001	Timing, safety, and efficacy of thoracoscopic evacuation of undrained post-traumatic hemothorax. *Am Surg*. 2006;67:1165–1169.	Low	(n = 24) Single center prospective observational review of patients undergoing VATS before and after 3 days post-injury. Reported decrease hospital LOS and lower empyema rates in early intervention group. Less operative difficulty noted in early VATS arm

Table 30.3 (continued)

Authors	Year	Reference title	Evidence quality	Study summary
Ziapour et al.	2020	Timing to perform VATS for traumatic-retained hemothorax (a systematic review and meta-analysis). *Eur J Trauma Emerg S*. 2020;46:337–346.	Moderate	(n = 476) Meta-analysis of six cohort studies evaluating optimal time to VATS. Evaluated three time frames (1–3 days, 4–6 days, and >7 days). Found higher rate of procedural success for 1–3 and 4–6 day groups with associated decreased hospital LOS compared to >7 day group

VATS video assisted thoracoscopic surgery, *LOS* length of stay

of technique and timing have become increasingly more relevant. As it stands, no high-quality randomized data exists specifically exploring the question of optimal timing of VATs for retained hemothoraces. On the whole, however, the aggregate data from several well-designed and large series studies suggest an increasing clinical benefit with prompt surgical intervention within a week of diagnosis, with some evidence that ultra-early interventions (<3 days) may further improve upon these results.

Review of Recommendations

- Video-assisted thorascopic drainage for retained hemothoraces should occur with 4–6 days of injury (evidence quality moderate; moderate recommendation).
- Outcomes for video-assisted thorascopic drainage are improved drainage 2–3 days post-injury (evidence quality weak; weak recommendation).

Personal View of the Data

In our experience, earlier intervention for retained hemothoraces has led to improved outcomes and chances of procedural success at our institution. We regularly perform follow-up X-rays after chest tube insertion and in subsequent days of hospitalization. When a radiograph shows concern for a moderate-sized retained hemothorax, our treatment algorithm includes prompt cross-sectional chest imaging and evaluation for potential thoracoscopic drainage ideally within a week of injury. Additionally, all patients with hemothoraces and rib fractures are also evaluated for possible rib stabilization concurrently with the VATS. While appropriate management of a retained hemothorax is crucial, we have also implemented strategies aimed at reduction of these complications, including thoracic irrigation at the time of initial chest tube placement. We feel these interventions and prompt surgical management of complications related to retained hemothoraces result in improvement in patient's pain, respiratory function, time to ICU discharge, and overall recovery.

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Part VIII

Ethics

Donation After Cardiac Death in the Emergency Department

31

Lisa M. Kodadek, Allan B. Peetz, and Peter Angelos

Introduction

Trauma patients account for approximately 30% of all deceased organ donors [1]. It is feasible to procure and transplant organs from trauma patients after declaration of death by either neurologic criteria or cardiac criteria. Neurologic criteria prove irreversible cessation of whole brain function, even while circulation continues. These donors are sometimes referred to as "brain-dead" donors. Death by cardiac criteria requires three simultaneous and irreversible findings: (1) unresponsiveness, (2) apnea, and (3) absent circulation [2]. Technically, it is more accurate to refer to this as "circulatory death" instead of "cardiac death"—while the heart is usually the source of circulation, other sources may include cardiopulmonary resuscitation (CPR), heart-lung machines, and extracorporeal membrane oxygenation (ECMO) [3]. These donors are also referred to as "donation after cardiac death" (DCD) donors. These criteria are considered more traditional because neurologic criteria for brain death were only developed in 1968 with the publication of the Harvard

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Committee report [2, 4]. However, donation after cardiac death carries with it more clinical challenges including poor organ quality and adverse recipient outcomes [5]. Ethical and logistical challenges of donation after cardiac death may also limit its utility [6].

Donation after cardiac death is either termed controlled or uncontrolled. Controlled DCD involves planned withdrawal of life-sustaining therapies when resuscitation attempts are not consistent with patient preferences and consent for donation has been obtained. Additional requirements of controlled DCD donation include: the patient must expire typically within 60 min after removal of life-sustaining therapies, death must be certified, and only then are organs procured if they are viable. If the patient does not die within 60 min, the organs are no longer viable for transplantation because of prolonged warm ischemia time [7]. The Institute of Medicine guidelines recommend a five-minute observation period after the onset of circulatory arrest, apnea, and unresponsiveness in order to certify death [8].

Uncontrolled DCD occurs when organ procurement follows unexpected cardiac arrest and/or when attempted resuscitation efforts are not successful. This is the type of organ donation that typically applies to trauma patients declared dead by cardiac criteria in the emergency department (ED) [6]. The Maastricht Classification organizes donation after cardiac death into four categories: I—dead on arrival, II—unsuccessful resuscitation, III—awaiting cardiac death, and IV—cardiac death in a brain-dead donor. Controlled donation may take place in Maastricht III patients; uncontrolled donation may take place in Maastricht I, II, and IV patients [9].

Nearly 80–90% of organs from deceased trauma donors are procured after determination of death by neurologic criteria and typically in an intensive care unit (ICU) setting [10]. While technically feasible, only a small proportion of trauma patients become DCD donors, and this is typically controlled donation [11]. In contrast, uncontrolled DCD donation in the ED is extremely rare, with only a few cases reported in the literature [12–14]. Some have even argued that the expected organ yield from trauma patients after cardiac death is too low to justify the practice given the considerable ethical and logistical challenges [11]. The purpose of this chapter is to make recommendations for organ procurement efforts after trauma patients are declared deceased by cardiac criteria in the ED.

Search Strategy

The GRADE approach utilizes a priori creation of a research question in the Population, Intervention, Comparator, Outcome (PICO) format (Table 31.1) [15, 16]. The literature query focused on injured adult patients declared deceased in the ED by cardiac criteria (P) who underwent organ procurement efforts (I) versus no organ procurement efforts (C). Critical outcomes of interest (O) were organ viability, rate of organ donation, and rate of successful organ transplantation.

Table 31.1 PICO Question

P (Population)	I (Intervention)	C (Comparator)	O (Outcomes)
Injured adult patients declared deceased in the emergency department by cardiac criteria[a]	Organ procurement efforts	No organ procurement efforts	Organ viability, rate of organ donation, rate of successful organ transplantation

[a]Cardiac criteria for death require three simultaneous and irreversible findings: (1) unresponsiveness, (2) apnea, and (3) absent circulation

"emergency service, hospital"[MeSH Terms] OR emergency department[Text Word] OR "injuries"[Subheading] OR "wounds and injuries"[MeSH Terms] OR "trauma patients" [tiab] OR trauma[Text Word] AND "transplantation"[Subheading] OR "transplantation"[MeSH Terms] OR transplantation[Text Word] OR "tissue and organ procurement"[MeSH Terms] OR "organ transplantation"[MeSH Terms] OR organ donation[Text Word] AND "death"[MeSH Terms] OR "circulatory death"[Text Word] NOT "brain death"[tiab] AND "Adult"[MeSH Terms] AND "Humans"[MeSH Terms] AND "United States"[Text Word]

Fig. 31.1 Literature search strategy

A systematic literature search of PubMed, MEDLINE, and the Cochrane Library was completed in April 2020 to identify English language publications of interest. Since trauma DCD donation in the ED is a rare event, neither date restrictions nor article type restrictions were utilized to ensure all relevant articles were captured. An initial search using the terms "trauma patient organ donors" [Word Text] yielded 1068 articles. A secondary search used a more focused search strategy (Fig. 31.1). This search yielded an additional 312 articles. Title and abstract screens were performed for all 1380 papers identified through both search strategies. Among the articles screened, 28 articles published between 1996 and 2019 were selected for full text review. Articles were then excluded if they were editorials, survey studies, or if they did not potentially include trauma patients who were declared deceased by cardiac criteria. Given the limited number of trauma patients declared deceased by cardiac criteria in the ED who then became organ donors, location of death was not considered an exclusion criterion. ICU donors were also included since trauma patients are frequently cared for in the ED followed by the ICU. After full text review and appropriate exclusions, 11 articles published between 2005 and 2019 were included in the qualitative analysis. A quantitative meta-analysis was not completed secondary to heterogeneity of the studies selected for inclusion. Validated Grading of Recommendations Assessment, Development and Evaluation (GRADE) methodology was utilized for assessment of the aggregate quality of the evidence [15, 16] (Table 31.2).

Table 31.2 Summary of evidence for trauma patient organ donors declared deceased by cardiac criteria or deceased by brain death criteria after traumatic cardiopulmonary arrest and associated transplantation outcomes

Study	Design	GRADE quality of evidence	Number of potential DCD trauma donors	Number of potential deceased by brain death trauma donors[a]	Outcomes (organ viability, rate of organ donation, rate of successful organ transplantation)	Study overview
Magliocca, 2005 [17]	Retrospective cohort, single center in US, 3.5 years	Moderate	14	0	2/14 (14.3%)—Non-viable organs (cardiac activity at 60 min) 2/14 (14.3%)—Organs medically inappropriate for transplant 10/14 (71.4%)—Successful transplantation	DCD with ECMO-supported donors. Increased organ donor pool by 33%. ICU only. No ED donors.
Schnüriger, 2010 [18]	Retrospective cohort, single center in US, 3.5 years	Low	0	11	4/11 (36.4%)—Family declined 3/11 (27.3%)—Poor organ function 1/11(9%)—Cardiovascular death 3/11 (27.3%)—Successful transplantation	11/263 (4.2%) patients who underwent EDT with ROSC became brain dead donors. ICU only. No DCD donors. Only 1.1% of all trauma patients who underwent EDT became organ donors.
Raoof, 2011 [19]	Retrospective cohort, single center in US, 3 years	Low	0	155	14/155 (9.0%)—Family declined 15/155 (9.7%)—ME refused 15/155 (9.7%)—Poor organ function or logistics concern 92/155 (59.3%)—Cardiovascular death 19/155 (12.3%)—Successful transplantation	Brain dead donors in ICU only. No ED donors. No DCD donors. Organ procurement successful in 7.5% of all patients who presented with traumatic cardiopulmonary arrest.

Study	Design	GRADE quality of evidence	Number of potential DCD trauma donors	Number of potential deceased by brain death trauma donors[a]	Outcomes (organ viability, rate of organ donation, rate of successful organ transplantation)	Study overview
Faucher, 2014 [20]	Retrospective cohort, EMS network/ multiple hospitals in France, 5 years	Low	0	22	6/22 (27.3%)—Family declined 4/22 (18.2%)—Hemodynamic collapse 2/22 (9%)—Medical contraindication 1/22 (4.5%)—Administrative issue 9/22 (41%)—Successful transplantation	Brain dead donors in ICU only. No DCD donors. No ED donors.
de Freitas, 2015 [14]	Retrospective cohort, single center in Brazil, 1 year	Very low	29	27	18/29 (62%)—DCD donors with successful transplantation 11/27 (41%)—Deceased by neurologic criteria with successful transplantation	8/18 (44%) of DCD donors were from the ED. no explanation of protocol or logistics.
Joseph, 2015 [5]	Retrospective cohort, all transplantations in the US by UNOS, 12 years	Moderate	8724	NR	8724/90,586 (9.6%) trauma donors were DCD donors and the remainder were deceased by neurologic criteria. Proportion of DCD donors increased from 3.1% to 14.6% over the study period.	Proportion of DCD donors from ED not reported. No explanation of protocol or logistics.

(continued)

Table 31.2 (continued)

Study	Design	GRADE quality of evidence	Number of potential DCD trauma donors	Number of potential deceased by brain death trauma donors[a]	Outcomes (organ viability, rate of organ donation, rate of successful organ transplantation)	Study overview
DeVita, 2016 [13]	Prospective cohort, two academic centers in U.S., 17 months	Low	11	0	3 donors underwent procurement, but no organs were transplanted due to prolonged warm ischemia. Article did not report whether the 3 donors were trauma or medical victims.	Uncontrolled DCD program in ED including both trauma and medical patients.
Love, 2016 [21]	Retrospective cohort, single center in US, 36 months	Low	0	11	5/11 (45.5%)—Donor procurement, transplantation rate not reported 3/11 (27.3%)—Cardiovascular death 3/11 (27.3%)—Family declined	No ED donors. Brain dead donors in ICU only. No DCD donors.
Dailey, 2017 [12]	Case report, one patient in US	Very low	1	0	1/1 (100%)—ED DCD donor underwent procurement with 2 kidneys successfully transplanted	Case report of a DCD trauma donor from ED. LUCAS chest compression system was used to provide CPR in the ED until transfer to OR. Resource intensive.
Cameron, 2018 [1]	Systematic review and meta-analysis, 27 studies	NA	NA	NA	NA	Study of donor conversion rate in trauma patients. Only 4 of 27 studies included DCD donors and all are already included individually in this table [18–21].

Study	Design	GRADE quality of evidence	Number of potential DCD trauma donors	Number of potential deceased by brain death trauma donors[a]	Outcomes (organ viability, rate of organ donation, rate of successful organ transplantation)	Study overview
Ackerman, 2019 [22]	Retrospective cohort, all transplantations in the US by UNOS, 30 years	Low	4661 DCD trauma donors between 2007 and 2016	NR	NR	Proportion of DCD donors from ED not reported. No explanation of protocol or logistics.

GRADE—Grading of Recommendations Assessment, Development and Evaluation
US—United States
DCD—Donation after cardiac death
ECMO—Extracorporeal Membrane Oxygenation
ICU—Intensive care unit
ED—Emergency department
EDT—Emergency department thoracotomy
ROSC—Return of spontaneous circulation
ME—Medical Examiner
EMS—Emergency Medical Services
NA—not applicable
NR—not reported
CPR—Cardiopulmonary resuscitation
OR—Operating room
[a]Post traumatic cardiac arrest with successful resuscitation and return of spontaneous circulation

Results

The studies included 8 retrospective cohort studies [5, 14, 17–22], one prospective cohort study [13], one case report [12], and one systematic review [1]. Magliocca described a single center DCD Protocol using ECMO support for in situ, normothermic perfusion of abdominal organs following cardiac death [17]. This retrospective cohort study involved ICU patients who were deemed suitable for potential donation after cardiac death by the organ procurement organization (OPO). If family consented to DCD donation, the ECMO team cannulated the patient in the ICU. Life-sustaining therapies were then withdrawn under the direction of the ICU team. If the patient was declared dead within 60 min, the ECMO team began perfusion. The donor was then taken to the OR for controlled organ procurement. This protocol allowed for a donor pool increase by 33% when including both trauma and non-trauma patients. However, only 14 trauma patients over a nearly 3.5-year period were enrolled, and successful transplantation was only possible in 10 of the potential donors (kidney and liver transplantation only). Four potential donors were unable to donate secondary to medically inappropriate organs or cardiac activity present at 60 min after removal of life-sustaining therapies. The study was well-designed with a clear protocol. As a retrospective/observational study, data were low quality. However, a large effect size was present making the quality of evidence moderate.

Schnüriger reported results of a single center retrospective experience of organ donation following ED thoracotomy for injury [18]. All patients who presented to the ED after injury with no pulse or who lost a pulse in the ED underwent resuscitative thoracotomy per the institution's usual approach to care. In total, 263 patients underwent resuscitative ED thoracotomy over 3.5 years. Two-thirds of these patients were declared deceased in the ED and no organ procurement efforts were attempted. The remaining one third of patients regained a pulse and survived to the operating room (OR). Of those patients who survived to the OR, 44% died in the OR and 56% survived to the ICU. In total, 11 patients out of 263 were identified as potential organ donors after meeting neurologic criteria for brain death. Of the 11 potential donors, only three went on to become organ donors. Eight patients did not become organ donors because family declined consent, poor organ function, or cardiovascular death prior to donation. Just 1.1% of ED thoracotomy patients became donors. This study demonstrates the limited utility of organs from patients who underwent ED thoracotomy as part of their resuscitative attempts. This study was graded as low quality due to retrospective study design and imprecision.

Raoof reported a single center three-year experience with organ donation after traumatic cardiopulmonary arrest [19]. This study only included patients who were successfully resuscitated and then declared dead by neurologic criteria. Organ procurement was successful in 19/252 (7.5%) of all patients who presented to the trauma center with traumatic cardiopulmonary arrest. Of the patients who were successfully resuscitated but whose organs were not used, the majority of them had cardiovascular death after the donor network was contacted but before their arrival

to the hospital. This study was graded as low quality due to study design, imprecision, and risk of bias.

Faucher examined organ donation after traumatic cardiac arrest [20]. This was a five-year retrospective study conducted from 2004 to 2008 involving nine general hospitals and three departments in France. Of note, donation after cardiac death (neither controlled nor uncontrolled) was not allowed to be performed in France at the time of this study. All donors were declared deceased by neurologic criteria. Nine of 22 potential donors (41%) underwent successful transplantation. This study was low quality by GRADE assessment.

A retrospective cohort published by de Freitas described experience with organ transplantation from trauma donors in Brazil [14]. Over one year at a single center, there were 134 deaths from injuries. Most of these deaths (96/134, 72%) were from traumatic brain injury. Patient deaths occurred in the ICU (92/134), the ED (41/134), and the surgical ward (1/134). Among 134 trauma patients, 56 were identified as potential donors and families were approached for consent. Ultimately, 29 trauma patients became organ donors with 18 DCD donors and 11 donors after brain death. Almost half of the DCD donors (8/18) were from the ED. Family refusal was the most common reason a trauma patient did not become a donor. This study was graded as very low quality because of retrospective design, indirectness, and imprecision. Furthermore, there was no explanation of the clinical protocol for DCD donors after death was declared in the ED. There was no information about organ viability or transplant recipient outcomes. This was the only study that included both DCD donors and donors declared by neurologic criteria which limited the clarity of some of the data presented.

Joseph described US national trends in donation after cardiac death among trauma patients using the United Network for Organ Sharing (UNOS) registry between 2002 and 2013 [5]. This registry captured 8724 trauma DCD donors over the 12-year period. DCD donor proportion increased from 3.1% in 2002 to 14.6% in 2013. This study provided a comprehensive understanding of DCD donation among trauma patients in the USA. However, there was no report of the number of patients who became DCD donors in the ED nor any information about uncontrolled versus controlled approaches to DCD. Overall, this study was graded as moderate quality because of its retrospective nature and limited data, but overall this was well-designed and demonstrated the largest number of trauma DCD donors of any published report to date.

A prospective cohort study and program for uncontrolled DCD organ procurement program at two academic centers in the ED was published by DeVita [13]. All ED deaths were screened for potential participation. Over the 17-month study period, 18 potential donors were identified in the ED and 11 of these donors (61%) were trauma patients. Most of the trauma patients 7/11 (64%) had suffered traumatic cardiac arrest related to gunshot wounds. The DCD protocol was enacted six times. Only three donors had organs procured and the article did not specify whether these were trauma patients or medical patients. No organs were transplanted due to biopsies demonstrating prolonged warm ischemia. The authors described a

"massive preparatory effort" to conduct this prospective study and donation program, with no resultant transplanted organs. This study was well-designed but graded as low quality overall because of risk of bias due to allocation concealment, lack of blinding, and imprecision.

Love reported a retrospective cost analysis evaluation of DCD trauma donors [21]. Over the 36-month study period at a single center, 237 patients had traumatic cardiopulmonary arrest with 97% associated mortality. Only 5% of these patients were eligible for organ donation and 2% underwent procurement. The cost of resuscitation after traumatic cardiopulmonary arrest per survivor was US$1.8 million. Cost per survivor or per donor recipient was US$538,000. Eleven patients had return of spontaneous circulation after traumatic cardiac arrest and were then considered for organ donation and five patients underwent procurement. Of the six patients who did not undergo procurement, three died from cardiovascular collapse and consent was not granted for the other three patients. This study was graded as low quality due to its retrospective nature.

A case report of a trauma patient who became an uncontrolled DCD donor in the ED was reported by Dailey [12]. This patient was dropped off in front of the trauma center after sustaining a gunshot wound to the head. He arrived with inadequate respirations, bradycardia, and a normal blood pressure. The patient underwent resuscitation including intubation. Computed tomography demonstrated a transcranial gunshot wound with injuries including foreign bodies within the calvarium, bilateral subdural hematomas, numerous skull fractures, and extensive brain edema. The neurosurgical team deemed the patient's injuries nonsurvivable and the OPO was immediately notified. Family was contacted and they indicated that the patient would strongly desire organ donation if possible. The patient subsequently became pulseless and remained pulseless despite trial of chest compressions, vasopressors, and blood product resuscitation. A LUCAS chest compression system was applied to the patient and procurement efforts were mobilized. The patient was taken to the OR, the LUCAS system was discontinued, and the patient was declared deceased by cardiac criteria. The transplantation team and the OPO then proceeded with organ procurement. The authors reported that both of the donor's kidneys were successfully transplanted. This was a very resource intensive effort for those involved, but the authors demonstrated a feasible approach to DCD donation after cardiac death in the ED. This case report was graded as very low quality. However, it was included in the assessment because it very directly describes the procedure of interest in a manner that highlights logistical and ethical challenges of this approach to organ donation.

Cameron conducted a systematic review and meta-analysis in 2018 to determine the rate of donor conversion in trauma patients [1]. The authors found a pooled donor conversion rate for potential trauma patient organ donors of 48.1%. This systematic review included 27 studies and 123,142 trauma patients, but only four of these studies included trauma patients who became DCD organs. Each of these four studies were already included individually in the present review [18–21]. A GRADE assessment was not conducted for this study since it contributed no new data.

A retrospective analysis by Ackerman of all US transplantations between 1987 and 2016 included 191,802 donors total including trauma and non-trauma patients [22]. The number of trauma donors in 1995 was 2868 which increased by 13% to 3241 by 2015. Data submitted by members of the Organ Procurement Transplant Network demonstrated that proportion of donors after cardiac death was less than 5% in 2000 and greater than 15% in 2016. This study was graded as low and gave no data about proportion of DCD trauma donors in the ED. Organ recipient outcomes were not reported.

Only three studies inclusive of 41 patients in total specifically addressed the PICO question developed prior to the literature search [12–14]. Only 19 successful cases of transplantation were reported after organ procurement efforts among trauma patients declared deceased in the ED by cardiac criteria. Overall, the quality of evidence was assessed as low using GRADE methodology. This assessment is based on imprecision related to small sample size and few events, indirectness related to varying interventions and clinical protocols (such as LUCAS use), limited magnitude of effect, and considerable risk of bias.

Recommendations Based on the Data

In injured patients declared deceased in the ED by cardiac criteria, we conditionally recommend against organ procurement efforts. This recommendation is based on overall low quality of evidence; confidence in this assessment is limited based on the quality of evidence and the true effect may be substantially different from the estimate of the effect. However, this recommendation takes into account a very low rate of organ donation among trauma patients deceased after cardiac death, a very low rate of successful organ transplantation, and significant ethical, logistical, and resource challenges. This conditional recommendation is consistent with GRADE definitions of a conditional/weak recommendation recognizing the attendant implications for patients, clinicians, and policy makers. Clinician expertise is critical to ensure the highest quality care for trauma patients while attending to the ethical and logistical considerations around DCD donation after cardiac death in the ED. Considerable debate and stakeholder involvement are necessary to make policy. Organ procurement efforts for trauma patients declared deceased in the ED by cardiac criteria should generally only take place as part of an organized clinical program for uncontrolled DCD donors with appropriate staff education and support from stakeholders including patients, medical providers, and the community.

Summary of Recommendation

- In injured patients declared deceased in the ED by cardiac criteria, we conditionally recommend against organ procurement efforts (evidence moderate; strong recommendation).

- Organ procurement efforts for trauma patients declared deceased in the ED by cardiac criteria should generally only take place as part of an organized clinical program for uncontrolled DCD donors with appropriate staff education and support from stakeholders including patients, medical providers, and the community (evidence quality high; strong recommendation).

A Personal View of the Data

A trauma physician's primary professional and ethical concern is the well-being of the trauma patient. When resuscitating a trauma patient in the ED, organ donation is an ethically problematic motive and should not be the sole indication to continue resuscitative efforts in a patient with nonsurvivable injury. While donation is critically important for patients in need of life-saving organs, the trauma physicians motivated by the potential for organ donation will find themselves in conflict with their duties to their patient by violating the ethical principle of respect for persons [23]. Prolonging the patient's life by extending futile care violates the principle of nonmaleficence by exposing the patient to unnecessary pain, suffering, and harm [24].

The medical and ethical literature considers DCD acceptable, however, this does not obviate significant concern among healthcare providers who may experience moral distress at the interface between end-of-life care and organ donation [25]. Physicians are obliged to honor the "dead-donor rule" in order to maintain public trust in national organ donation networks and health systems [26–28]. This rule mandates that a patient be declared dead before the removal of life-sustaining organs for transplantation [26]. It is both unethical and illegal to cause death by procuring organs [2]. The pursuit of organ procurement before consent or resuscitation of patients only for the purpose of procuring organs is at the very least ethically problematic. Resuscitative efforts should be provided to trauma patients commensurate with potential benefit to the trauma patient rather than due to possible benefit to others if organs were procured. The trauma team must abide by professional ethics and treat the patient with life-saving means until the patient is declared brain dead or until the patient is clearly at risk of imminent death from cardiovascular collapse [6].

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Resuscitative Thoracotomy for Organ Donation

32

Mark Seamon and Jane Keating

Introduction

Resuscitative thoracotomy (RT) is considered a last chance effort for patients in traumatic cardiopulmonary arrest. It is most favorable for penetrating trauma victims with recently lost signs of life, especially those with an isolated stab wound to the chest [1]. Despite evidence of improving survival from this procedure in recent decades likely due to improvements in prehospital care and reduced transport times, overall survival remains poor (<2% survival for victims of blunt trauma and <9% survival for victims of penetrating trauma) [2]. More recently, some groups have suggested that outcomes other than survival may be important to consider, including the opportunity for organ donation. Every year, approximately 3000 patients in the United States die while awaiting organ transplant [3]. Similarly, trauma victims are often young and healthy, and therefore organ donation from this population has the potential to impact many lives. In fact, it is estimated that 1 donor can impact up to 8 lives through organ donation. Failing to recognize potential donors or obtain family consent appear to be the most important factor in limiting organ donation [4–6]. Many cultural challenges exist around the concept of organ donation especially in the African-American community despite being disproportionately impacted by an insufficient number of organ donors. The rates of successful donation among this trauma population is low.

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Table 32.1 PICO

Patients	Intervention	Comparator	Outcomes
Patients in traumatic arrest who undergo RT	Resuscitative thoracotomy	No resuscitative thoracotomy	Organ donation

Author	Journal	Year	Traumatic arrest (*n*)	Resuscitative thoracotomy (*n*)	Organs donated (*n*)
Traumatic arrest + Organs donation					
Raoof et al.	Am J Surg	2011	252	NA	26
Alarhayam et al.	J Am Coll Surg	2017	340	NA	24
Traumatic arrest + Resuscitative thoracotomy + Organs donation					
Schnuriger et al.	J Am Coll Surg	2010	263	263	11
Inaba et al.	Am Surg	2015	223	223	3 (donnors)

In the United States, the majority of transplants occur after donations from brain-dead, heart-beating donors. It is recognized that non-heart-beating donors are another source of viable organs, as long as warm ischemia time is minimized. Approximately 100,000 patients in the United States die annually from blunt trauma, often shortly after their injury, and therefore trauma patients undergoing RT represent a large potential source of donor organs from non-heart beating donors [7]. This chapter aims to understand the impact of resuscitative thoracotomy on organ donation in patients in traumatic arrest who undergo RT (Table 32.1).

Search Strategy

In the context of the poor survival rates following RT as well as the many factors which make organ donation challenging in the United States among trauma patients, this chapter provides a review of the current literature regarding the utility and challenges of RT for the purpose of organ donation. We performed a PUBMED search of the literature regarding organ donation for patients who have undergone RT following trauma. Overall, data is sparse in this specific patient population (Figs. 32.1 and 32.2).

Our search strategy was to use the terms "*Trauma and Organ Donation and Resuscitation"* on PUBMED. This resulted in 194 publications which were then reviewed and included in this chapter if relevant to the research question described.

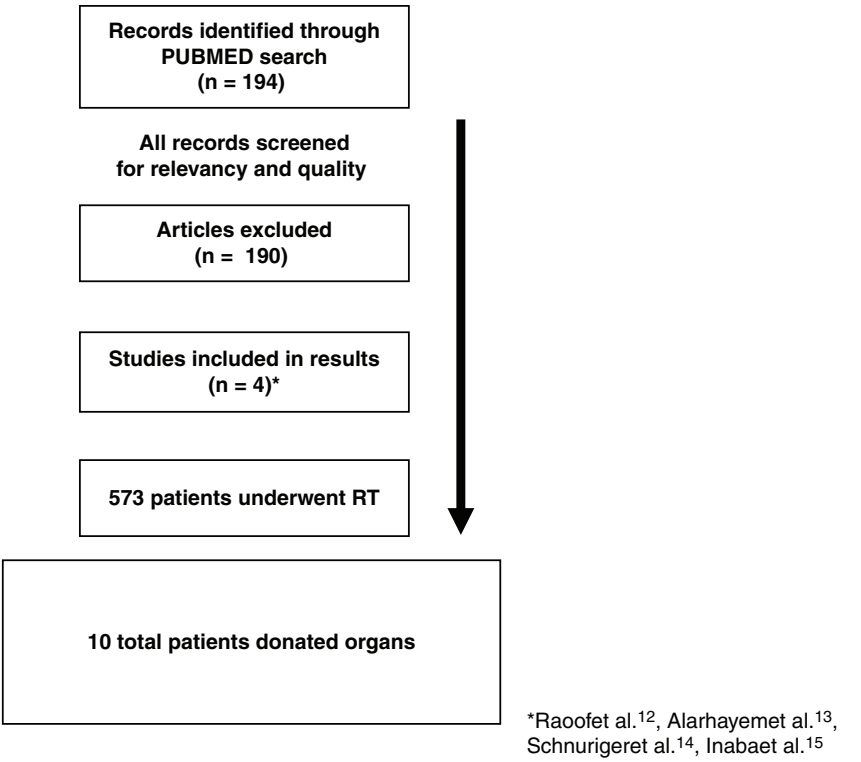

Fig. 32.1 Total number of organs donated following resuscitative thoracotomy as identified through literature search

Traumatic arrest + Organ donation	12. Raoof et al. 2011 13. Alarhayem et al. 2017
Traumatic arrest + RT + Organ donation	14. Schnuriger et al. 2010
Traumatic arrest + FAST + Organ donation	15. Inaba et al. 2015

Fig. 32.2 Relevant literature regarding traumatic arrest and organ donation

Results

Early Feasibility Studies for Feasibility of Organ Donation in Trauma Patients

In 1996, Wisner and Lo performed a retrospective cases series including blunt trauma victims who were declared dead in the emergency department at a level one trauma center (University of California, Davis) in order to review the feasibility of organ donation in trauma patients. Of the 201 patients reviewed, 45 families were documented as requested for tissue donation, and of these patients, 44% of families consented. Factors precluding request for organ donation included age, prolonged interval between injury and death declaration, and a lack of timely available next of kin. In this retrospective review, they assigned an age restriction of 60 years, a trauma-to-death interval of less than 60 minutes, and the absence of injuries precluding donation or in situ perfusion in order to produce a potential donor yield of 19% of all 201 patients reviewed. They then assumed a similar consent rate of donation, and concluded an approximate 9% donor yield in their population [8].

The low rate of consent among families of potential solid organ donors is a major limiting factor in the success of organ transplantation. In order to explore factors associated with decision-making, in 2001 Siminoff et al. completed a retrospective review of donor eligible deaths at nine trauma hospitals in Pennsylvania and Ohio from 1994 to 1999. They found that family and patient sociodemographics (ethnicity, patient age, and cause of death), as well as prior knowledge of the patients' wishes, were significantly associated with willingness to donate [9]. Additionally, evidence shows that family support through the death and dying experience positively affects the donation rate, as does decoupling the process of brain death pronouncement and organ request [10].

Effects of Race on Organ Donation

In order to more fully understand the potential impact of culture and policy on organ donation in trauma patients, McCunn et al. compared the organ donation policies, consent rates, and number of organs transplanted from brain-dead patients following traumatic injuries in two urban trauma centers: The R Adams Cowley Shock Trauma Center (STC) in Baltimore, Maryland, and the Lorenz Bohler Hospital in Vienna, Austria. Although the numbers were small, they found that a "presumed consent" organ donation policy in Austria resulted in 100% of medically suitable patients going on to donation at the Vienna hospital. With the volunteer donation policy at STC, 46% went on to donation. They concluded that a higher organ donation rate in the United States could result in a greater number of organ transplants from patients who die after traumatic injury. Additionally, there did not appear to be any significant difference in ethnicity between families who accept and those who refuse organ donation after traumatic brain death declaration at STC (56% of patients who refused were African American, while 48% of patients who refused were Caucasian) [11].

Organ Donation Following Traumatic Cardiac Arrest is Infrequent

Given the potential for increased organ utilization from young and previously healthy trauma victims, Raoof et al. attempted to determine the variables that would predict successful organ donation in patients who underwent cardiopulmonary resuscitation (CPR) after trauma. 252 patients who either underwent CPR in the field or in the trauma center were identified from 2007 to 2010. There were a total of 39 (15.5%) survivors and 213 (84.5%) fatalities. Of the 213 fatalities, 19 patients (8.9%) became organ donors. 26 total organs were harvested, including 15 kidneys, 6 livers, 4 hearts, and 1 pancreas. Of note, a significant percentage (64.7%) suffered cardiac arrest before the arrival of the donor network, which the authors cited as the greatest barrier to organ donation in trauma patients after cardiopulmonary arrest, which was followed by lack of family consent and refusal by the medical examiner. A total of 30 patients underwent RT. Of the 19 donors, only 1 of these patients had a RT. Of the 194 nondonor patients, 29 patients had undergone an RT. There was no significant difference between the incidence of RT among both the donor and non-donor groups [12].

In a similar study in 2017, Alarahayem et al. attempted to address whether organ donation was an unexpected benefit of aggressive resuscitation in trauma patients presenting without signs of life. In their study, they reviewed 340 patients that presented to their Level I trauma center with no signs of life (pulse = 0 beats/min; systolic blood pressure = 0 mmHg, GCS = 3, with no evidence of neurologic activity), 93 (27.4%) underwent RT. They studied both patient survival and major organ donation. The overall survival to discharge of all patients presenting with no signs of life was 2.1% which was comparable to an analysis of the National Trauma Data Bank. Of their 333 non-survivors, 12 patients (3.6%) donated major organs (16 kidneys, 2 hearts, 4 livers, 2 lungs). All 12 of these patients had severe TBI, additionally three of these 12 (25%) patients received RT. There was no significant difference in organ donation among patients who underwent RT and those who did not. They concluded that although organ donation rates remain low, there may be an under-recognized benefit of aggressive resuscitation (including RT) in trauma patients presenting without vital signs [13].

Organ Donation Following RT is Infrequent

While the previous studies investigated all patients presenting with no signs of life who underwent continued resuscitation, Schnuriger et al. conducted a retrospective study including only patients who underwent RT from 2006 to 2009 at Los Angeles County and University of Southern California Medical Center. A total of 263 patients were studied. They found that the overall survival to discharge was 1.9% ($n = 5$), while 4.2% ($n = 11$) became potential organ donors. Five of the potential organ donors were injured by a blunt mechanism of injury. Of the 11 potential donors, 8 patients did not donate. Four of these eight patients had family which

declined donation. Three of the patients had poor organ function, and one patient expired due to cardiopulmonary collapse. From the 3 successful donors, 11 organs were harvested (6 kidneys, 2 livers, 2 pancreases, and 1 small bowel). Of the 3 successful donors, 2 had sustained blunt injury and 1 had sustained a penetrating mechanism of injury. They also noted that all 3 organ donors became pulseless either in the field or en route, with transportation time ranging from 12 to 15 minutes. Despite the small number of donors and organs donated, they concluded that one of the positive outcomes after traumatic arrest following RT is organ procurement, which directly impacts society and should be considered when analyzing the value of RT [14].

FAST Examination May Predict Successful Organ Donation Following RT

Many studies have attempted to predict the survival of patients undergoing RT following both blunt and penetrating trauma, however, little is known about the factors predicting successful organ donation. In a prospective study from 2010 to 2014, Inaba et al. found that the parasternal/subxiphoid cardiac views of the Focused Assessment Using Sonography of Trauma (FAST) could discriminate between survivors and nonsurvivors undergoing resuscitative thoracotomy (RT). They also found that the FAST examination predicted patients who went on to be organ donors. Specifically, 187 patients were studied in traumatic arrest and underwent FAST looking for both cardiac motion and pericardial fluid. 51.3% of patients suffered penetrating trauma. RT or clamshell thoracotomy was performed in all patients. In 3.7% of cases, FAST examination was noted to be inadequate. Overall survival was 3.2% and 1.6% of patients progressed to organ donation. Cardiac motion was 100% sensitive and 73.7% specific for the identification of survivors and organ donors. All survivors and organ donors had adequate view on FAST examination and all had evidence of cardiac motion, similarly no patient in the study without cardiac motion survived or became an organ donor. The addition of pericardial fluid, or those with inadequate results did not improve the sensitivity for the identification of survivors or organ donors. They concluded that FAST may represent an effective method of separating those who did not warrant the risk and resource burden of RT from those who may survive or go on to becoming organ donors [15].

Recommendations Based on the Data

- Given insignificant evidence to suggest improved organ donation rates following a more liberal use of RT, we would suggest continuing to follow the Eastern Association for the Surgery of Trauma (EAST) guidelines for RT following trauma (evidence quality low, weak recommendation) [16].

- We recognize the potential source of organ donors among the trauma population and encourage research into factors that would improve organ donation rates and therefore could make a significant impact on the survival of patients waiting for lifesaving transplants (evidence quality low, weak recommendation).

A Personal View to the Data

When contemplating the benefits of resuscitating a patient in traumatic cardiac arrest, including both survival and organ donation, it is important to also consider the risk of RT to the providers involved in performing the procedure. Our group studied the risk of occupational exposure during RT. One thousand three hundred sixty participants (23% attending, 59% trainee, 11% nurse, 7% others) were surveyed after 305 RTs. Overall, 22 occupational exposures were documented, resulting in an exposure rate of 7.2% (95% confidence interval [CI], 4.7–10.5%) per RT and 1.6% (95% CI, 1.0–2.4%) per participant. While human immunodeficiency virus/hepatitis prevalence in trauma patients (0–16.8%), we suggested that with proper precautions, the risk of occupational exposure is low, and should not deter providers from performing RT [17].

At our own institution, we use RT liberally (Fig. 32.3) [18]. As a result of the high number of penetrating trauma patients transferred by police, transport times are presumed to be short and largely unknown at the time of resuscitation. Additionally, because patients are not closely monitored for signs of life in a police vehicle, the exact moment of loss of these signs is usually unknown. Likewise, as discussed previously, we have shown that RT is safe when performed with proper precautions. As a result, the vast majority of pulseless patients that have suffered penetrating injury arriving at our institution will undergo RT. For blunt trauma victims, we reserve RT for patients who lose pulses in the trauma bay. Additionally, despite having obviously devastating injuries, patients with severe TBI often from gunshot wounds to the head are aggressively resuscitated and admitted to the ICU. This allows for a more controlled environment and the passage of time from injury until death. It may also allow for the recognition of these patients as potential donors and an opportunity to obtain family consent.

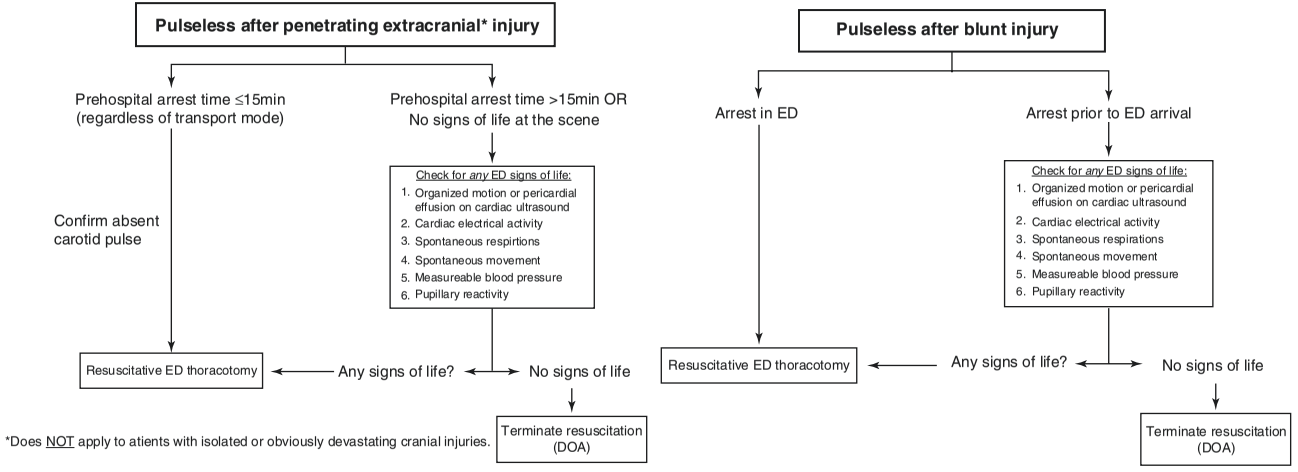

Fig. 32.3 Our level one trauma center's algorithm for resuscitative thoracotomy

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Resilience Training for the Trauma Surgeon

33

Ava Ferguson Bryan, Kyra Nicholson, and Tanya L. Zakrison

Introduction

> Resilience is great if you're getting punched in the face, but it does nothing about the fact that you're actually getting punched in the face.
>
> —Stanley Kurek, DO, "EAST 2016 Presidential Address: Resilience" [1].

The literature on resilience in surgery has exploded over the past decade, with peer-reviewed references in PubMed jumping from 46 in 2009 to 232 in 2019. The issue of resilience for trauma surgeons is especially salient as our work, by definition, exposes us to traumatic events on a regular basis. This places us at high risk for psychiatric sequelae such as depression, burnout, and post-traumatic stress disorder (PTSD), among others [2, 3]. Newer terms, such as "moral distress," "moral injury," and "compassion fatigue" continue to emerge, all related to exposure and response to trauma within the political, social and economic confines of medicine and society [4, 5]. "Resilience" and "resilience training" are colloquially seen as a balm to these stressors, but the exact meanings and uses of these phrases vary considerably and overlap with several adjacent phrases. Therefore, before we begin analyzing what we currently know about resilience and trauma surgery, we must start with definition of terms.

"Resilience"

The Oxford English Dictionary lists the "literal applications" of resilience as: "[1] The action or an act of rebounding or springing back; rebound, recoil; [2] Elasticity; the power of resuming an original shape or position after compression, bending,

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etc...” [6]. Adapted to describe personal and interpersonal dynamics, The American Psychological Association defines resilience as: “The process of adapting well in the face of adversity, trauma, tragedy, threats, or significant sources of stress—such as family and relationship problems, serious health problems, or workplace and financial stressors” [7]. They further clarify that “as much as resilience involves ‘bouncing back’ from these difficult experiences, it can also involve profound personal growth.”

“Burnout”

While lack of resilience is frequently linked to burnout, the two are distinct entities. Burnout is “a response to prolonged exposure to occupational stress encompassing feelings of emotional exhaustion, depersonalization, and reduced professional efficacy” [8, 9]. Significant attention to burnout in physicians and surgeons has emerged over the past two decades. Burnout has many potential adverse consequences including absenteeism, increased commission of medical errors, depression, and even suicide [10].

“Moral Distress”

First defined by Andrew Jameton, PhD in his 1984 book *Nursing Practice: the Ethical Issues*, “moral distress” refers to “the psychological distress of being in a situation in which one is constrained from acting on what one knows to be right” [4]. This differs from “moral injury” which, originally applied to the experience of war, is perpetrating, failing to prevent, or bearing witness to acts that transgress deeply held moral beliefs and expectations [11]. To illustrate the distinction using examples from the daily clinical work of trauma surgeons: being unable to provide a patient access to the treatment or rehabilitation support they need because of lack of insurance may cause moral distress, while discharging a patient back into the conditions that led to their firearm injury may cause both moral distress and moral injury.

“Compassion Fatigue”

Compassion fatigue is defined as “stress resulting from exposure to a traumatized individual” [5]. This condition is characterized by emotional and physical exhaustion leading to a diminished ability to empathize or feel compassion for others, and can manifest as burnout [5, 12]. Compassion fatigue is closely related to secondary traumatic stress (STS) or vicarious trauma [5]. Those who care for trauma patients are exposed to secondary trauma as a necessary condition of their practice [13]. Female trauma surgeons, in particular, tend to experience higher rates of

compassion fatigue (as they do burnout) compared to their male trauma surgery counterparts [14].

"Trauma"

Everyone reading this chapter may be an expert in the assessment and management of patients with traumatic injuries. However, "trauma" extends far beyond gunshot wounds and fractured bones, especially when considered from the perspective of the trauma surgeon and trauma team in the context of moral injury, compassion fatigue, secondary traumatic stress, and the other risk factors for burnout described above. The typical trauma team not only operates on lacerated organs and blood vessels while managing intracranial hemorrhage; they perform this care in the context of treating patients who are the victims of systemic racism, unsafe communities, and food insecurity, among others. The repeated exposure to the trauma of others places trauma surgeons at risk of developing post-traumatic stress disorder (PTSD). The Diagnostics and Statistical Manual of Mental Disorders (DSM-5), acknowledges secondary trauma as a risk factor for developing PTSD and reserves a dedicated diagnostic criterion for first responders and those routinely exposed to trauma (e.g., trauma surgeons) [DSM-5].

Furthermore, discrimination faced along lines of gender, race, class, ethnicity, training, sexual orientation, gender identity, religion or other, adds an additional dimension of potential trauma experienced by surgeons. The myriad stressors affecting diverse trauma surgeons practicing in the United States was well described in the Eastern Association for the Surgery of Trauma's (EAST) first plenary session #EAST4ALL: An Introduction to the Equity, Quality and Inclusion Task Force [15]. In the largest survey to date of trauma surgeons, 58% of female trauma surgeons and 48% of trauma surgeons of color experienced or witnessed discrimination in the preceding 12 months [16].

Racial trauma and race-based traumatic stress have been described in the general population but are as-of-yet unexplored in the context of the experience of trauma surgeons. Racism is defined as a system of structuring opportunity and assigning value based on the social interpretation of how one looks (what we call "race"), that unfairly disadvantages some individuals and communities, unfairly advantages other individuals and communities, and saps the strength of the whole society through the waste of human resources [17]. Racial trauma is the cumulative effect of racism on an individual's mental and physical health [18] and has been linked to feelings of anxiety, depression, suicidal ideation, and physical health issues—yet remains understudied [19, 20]. Racial trauma can also be experienced vicariously by trauma surgeons when patients who look like them experience racism in the trauma bay [21, 22].

Finally, trauma surgeons are acutely aware of systemic trauma, which refers to the contextual features of environments and institutions that give rise to trauma, maintain it, and impact posttraumatic responses [23]. Structural violence, which

represents the institutional structures and policies that directly or indirectly cause psychological, emotional, economic, spiritual, physical, or sexual harm to particular individuals or specific groups of people, leads to systemic trauma [24]. Knowing that our patients, colleagues, friends, and families experience this in addition to ourselves, is itself a source of trauma.

"Trauma Informed Care"

Trauma informed care (TIC) "endeavors to do no harm, i.e. reducing potentially traumatic aspects of treatment and the delivery of care to avoid re-traumatizing patients," and "shares the goals of patient-and family-centered care, but adds further specific attention to mitigating the impact of potentially traumatic medical events and treatment" [25].

Search Strategy

We queried the PubMed for publications categorized with the terms "trauma surgery" OR "trauma surgeon" AND "resilience" OR "resilience." Results were limited to those written in the English language, without limit on time since publication. Articles were hand screened for relevancy and references examined for additional works falling outside the search parameters. Articles primarily related exclusively to trauma nursing, trauma researchers, or trauma patients were excluded from the analysis (Table 33.1).

Results

The literature clearly and consistently supports the message that surgeons suffer unacceptably high rates of burnout and depression. Shanafelt et al. in 2009 found that 40% of surgeons were burned out, 30% had depression, and 28% had a mental quality of life score greater than half a standard deviation below the norm [2]. Dimou et al. performed a systematic review of burnout in surgeons in 2016 and found that more than half of trauma surgeons (53%) were at the highest risk of burnout compared to other surgical specialties. Women were at particular risk [26]. In fact, in a recent 2021 survey, only 43% of trauma surgeons were satisfied with their work-life balance, and 61% reported burnout [27].

Table 33.1 PICO

P	I	C	O
Patients treated by trauma surgeons	Resilience training	No resilience training	Increase/decrease, PTSD, compassion fatigue, empathy, burnout

There is no study of resilience among trauma surgeons, nor documented interventions aimed at increasing resilience among trauma surgeons. Despite this, the topic has clearly entered the professional lexicon of trauma surgery, as evinced by the 2016 EAST presidential address on resilience. In this address, Dr. Stanley Kurek breaks resilience down into eight steps: (1) acceptance of change, (2) manage your emotions, (3) self-empowerment, (4) prepare, (5) staying busy and working, working, working; (6) professional networks; (7) reflect, and (8) give help [1].

Existing Guidelines and Recommendations

The American College of Surgeons' (ACS) statement Discrimination, Harassment, and Bullying declares that these behaviors create a hostile work environment that can compromise patient safety and jeopardize patient outcomes, in addition to damaging the well-being of staff, affecting professional relationships, physical health, mental health, and job satisfaction [28]. The ACS acknowledges that implicit bias may contribute to discrimination unless institutions commit to adequate training and cultural change. The Eastern Association for the Surgery of Trauma's Equity, Quality, and Inclusion in Trauma Surgery Practice Task Force (#EAST4ALL) statement includes the following: "We believe that as trauma surgeons, we should all have the same opportunities for *limitless professional growth, expression of ingenuity and academic development* regardless of background, gender, race, social class, sexual orientation or identification, language or any perceived 'difference' that is viewed with hostility—subtle or overt—by others. We grow better when we support each other as a collective of trauma surgeons dedicated to improving outcomes for our patients and their communities" [29]. Most trauma organizations, especially in light of recent national events regarding the preventable violence and loss of life of Black men, women, and transgender individuals at the hands of law enforcement officers, are increasingly recognizing their role in combatting racism and discrimination within their profession and within society at large. Statements to this end have been issued by EAST [30], the American Association for the Surgery of Trauma [31] and the Western Trauma Association [32].

Recommendations Based on the Data

The data on resilience training for trauma surgeons is non-existent, and therefore no recommendation can be made at this time based on formulation of the PICO question and evidence evaluation using the Grading of Recommendations, Assessment, Development, and Evaluation (GRADE) approach. However, the data on rates of burnout, depression documented among surgeons and PTSD among trauma surgeons underlines how essential this training, along with a full complement of mental healthcare, is for trauma personnel. While the issues of secondary traumatic stress, caretaker fatigue, and moral distress have been identified as challenges in

trauma nursing, there is no formal acknowledgment of the need for resilience training among trauma surgeons [33].

More than half of trauma surgeons by definition are exposed to traumatic events in their workplaces on a daily basis. They report symptoms of burnout yet there are still no standardized or evidence-based mechanisms of support or tools widely available for them as there are for other crew-resource management teams (i.e., pilots). Toolkits exist, however, to assist surgeons in countering professional trauma in the form of discrimination available through #EAST4ALL [34]. Individual wellness efforts can and must be embraced to counter the traditional but dying myth of a trauma surgeon's competency being dependent upon emotionlessness self-sufficiency. Wellness science must be adopted to ensure routine eating and sleep hygiene habits, exercise, and mindfulness methods for relaxation. This must be adopted in a manner that understands that our stressors and manifestation are different, and there is no one-size-fits-all solution. Importantly, being cognizant of societal-level trauma (such as racial trauma, sexism, and other forms of discrimination), workplace trauma, and their potential intersection can create urgent healthcare needs for our surgeons of color, especially African American and Black surgeons.

As a field, trauma surgery has started to embrace the importance of TIC, along with anticipation and treatment of PTSD for our patients who have suffered traumatic injuries. The ACS Committee on Trauma recommends in their 2018 statement on Post-Traumatic Stress Disorder in Adults, that implementing hospital-based violence intervention programs with a mental health component for victims of interpersonal violence should remain a priority [35]. We recognize that it is vital for the trauma surgeon to understand PTSD, as close to 50% of patients who survive firearm injury will develop the condition in 5 years after their injury, with concomitant increases in alcohol use and unemployment, all of which affects the pattern of reinjury [36]. PTSD also disproportionately affects African American, Latinx, and indigenous communities, and is twice as common in women as in men [37]. Failing to recognize, for instance, that aggressive behavior by patients represents Criterion E symptoms of PTSD, as opposed to a conduct disorder or being a "difficult patient," is a failure of our medical obligation to our patients. Similarly, failing to recognize the symptoms in one another, and failing to institute a system that cares for and prevents them, is a failure of our professional obligation to our colleagues and trainees. The ACS stresses the importance of measuring one's own propensity to burnout and well-being index on their Physician Well-Being Index website. On this page, surgeons can follow their own well-being over time, compare their scores to other physicians nationally and access free resources [38]. As PTSD and burnout are risk factors for suicide, all surgeons and at-risk individuals need to have availability to suicide prevention sites such as the National Suicide Prevention Lifeline in the United States, available 24/7 in English, Spanish, and the hard of hearing at 1-800-273-8255 [39].

Trauma informed care (TIC), which is centered around the consciousness that people come into any encounter with a set of experiences that greatly impact their ability to feel safe and to interact constructively with healthcare, and can be extended to our understanding of resilience training for the trauma surgeon, as well.

TIC-based treatments have been found effective in reducing the risk of PTSD or PTSD symptoms, reducing illicit substance use, and reducing the risk of depression. Although there is no trial-based evidence, expert opinion holds that TIC has the potential to reduce burnout [40] improve equity [41], and have other beneficial effects for staff, including trauma surgeons [42]. As trauma surgeons, we recognize the previous and ongoing trauma experienced by our patients. We understand the need to treat the psychological as well as the physical sources of injury. As trauma surgeons, we also need to be accepting of the same psychopathology in ourselves, given the nature of our work.

When the "bounce back" of resilience is emphasized, but not the personal growth, resilience training is merely productivity training disguised as mental healthcare. In fact, those that are perceived as "resilient" tend to deploy aggressive coping mechanisms, which artificially inflate their ego, in order to protect against psychological harm [43]. The downside to this is that these same traits of "resilience" actually inhibit self-awareness, limiting leadership potential. In fact, perceived resilient, bold leaders are actually unaware of their limitations and overestimate their leadership capabilities and current performance, stymieing personal growth and potentially harming the overall team mission to improve patient care.

We teach our residents that the "angry" young man who was the victim of firearm violence is, in fact, manifesting a psychiatric illness, namely PTSD, as a result of a violent system and not a weakness of character. We know that more than half of our patients with this injury will in fact develop PTSD. We teach our residents that it is our medical and ethical responsibility as trauma practitioners to care for the mental health sequelae of injury, while healing the physical wounds. Similarly, with more than half of our trauma surgeons experiencing burnout, it is abundantly clear that the problem is also not inherent to the trauma surgeon's "weakness of character" for being "non-resilient." The problem remains the system itself as the largest risk factor for burnout and harm.

Experts are careful to warn that while resilience is often employed in a "binary approach considering whether resilience is present or absent," a more honest and useful view would be "a continuum that may be present to differing degrees across multiple domains of life" [44]. It is important to distinguish resilience from compartmentalization, a common and necessary tool employed by trauma surgeons, which is a psychological defense mechanism used to avoid cognitive dissonance or mental discomfort when holding conflicting views or emotions within ourselves. The surgical 'thrill' of performing a technically swift and effective Emergency Department Thoracotomy contrasting with the reality of a human being moments away from preventable death is one such example. Similarly, internalization may be a maladaptive disorder when we choose to keep our problems to ourselves and may lead to depression, withdrawal, anxiety, and loneliness. Resilience training, when employed well, should focus on assisting trauma surgeons in unpacking that which they have compartmentalized, and in avoiding internalization.

We suggest that true resilience training entails at minimum (1) protected time for mental healthcare, (2) a culture of encouragement (resources that aren't merely "made available" but a consistent message normalizing their use), (3) paid sessions

with a mental health professional as proactive and preventive medicine. Wellness and self-care are important tools in the short term, as mentioned above, accessible from the American College of Surgeons [38]. Importantly, institutional leaders must make resilience and well-being a priority and ensure that the resources available are both culturally and structurally competent [45, 46].

However, we believe it is equally important to recognize that, for many trauma surgeons, the source of their secondary traumatic stress is their firsthand view of the harm that befalls patients as a result of specific ways in which society has been constructed and organized. Firearm violence is one example. Another timely example is the violence done to non-white persons by systemic racism and white supremacy, or misogyny leading to mass killings of women, men, and transgender individuals. Surgeons who experience secondary traumatic stress in the care of patients affected by these mechanisms may then experience moral distress when they are incapable of addressing the systems that they see as responsible for the harm befalling their patients, at times repeatedly.

In order to combat these mental and emotional harms, and in order to train the trauma surgeon to have resilience in the face of them, it might be necessary to look outside of traditional wellness training or even traditional counseling. In combatting moral distress that arises from seeing but not being able to address the larger, systemic mechanisms causing morbidity and mortality in the patients we care for, it might be necessary for resilience training for trauma surgeons to take the form of political activism and community organizing. This idea is taking root within other corners of medicine, but is arguably most important for the trauma surgeon given the nature of our work and the disease processes for which we care [47]. In Eisenstein's *New England Journal of Medicine* Perspectives piece entitled "To Fight Burnout, Organize," he defines burnout as "…the experience of caring for patients when you know that their socioeconomic and structural circumstances are actively causing harm in ways no medicines can touch" [47]. He then reminds us of the well-known parable of people drowning in a fast-flowing river which exhausts those on the shore rescuing them repeatedly, until one rescuer breaks away to identify the upstream cause of harm. Going upstream together is not just a logical and moral obligation, but also has a preventive and protective effect for both the patient, for future potential patients, and for the caregiver. Many resources exist for trainees and physicians to learn how to organize, including White Coats for Black Lives, Socially Responsible Surgery, Right to Health Action, and societal organizations including Black Lives Matter, among many others [48–51].

An important source of professional trauma and stress for surgeons is that caused by physiologic disruptions of sleep–wake cycles and acute-on-chronic sleep deprivation due to demands of the job. Sleep deprivation leads to a number of physical and emotional consequences related to the development of cancers, mood disturbances, burnout, and even suicidal ideation [52]. As national sleep guidelines recommend that adults sleep at least 7–9 h of quality sleep each night, trauma surgeons are not meeting these goals, with the average amount of sleep in one study falling short of recommended guidelines [52, 53]. Similarly, since research studying sleep in trauma surgeons indicates that it takes 3 days to return to baseline sleep patterns

after call, ensuring that overnight calls be spaced by 4 nights may potentially be a method to protect against burnout, however further research is needed [52]. Anecdotally, disordered eating patterns may also occur in trauma surgery due to demands of operating and patient care, but little to no literature exists on this topic. Occupational stress for trauma surgeons may also lead to alcohol and drug abuse [54]. Support systems should be available for screening as needed, and inquiry into the use of such substances recreationally or in an abusive fashion should be part of a routine psychological evaluation. Support must be made available for when trainees or faculty are identified as being at risk of drug or alcohol abuse.

Without formal training in medical school or residency, breaking bad news can become one of the most difficult parts of the trauma surgeon's job. Masiakos and Griggs describe the pain incurred with each episode of delivering such news and the effect it has on both family and surgeon [55]. In trauma surgery, given the statistics on trauma and in particular homicide affecting the young, it is common for us to tell parents that their child has died. The need to teach the skill of delivering bad news in trauma was identified more than 30 years ago, yet no formalized or standardized curriculum exists to lessen the psychological impact on both the provider delivering the news, or the loved ones receiving it [56]. Coupling trauma surgeons with palliative care experts may be a path forward for such curriculum development [57].

Summary of the Data

- The data on resilience training for trauma surgeons is non-existent (evidence quality weak; no recommendation).

A Personal View on the Data

In an effort to better understand resilience and the stress that surgeons and trainees endure (especially of color), as well as their proposed solutions, we interviewed colleagues with different levels of training and with a variety of upbringings on their views of resilience and burnout on trauma. While these accounts do not stand in for or necessarily represent all experiences, they provide a first-hand account of caring for our trauma patients on the South Side of Chicago, a disproportionate number of whom are young Black men.

1. Have you experienced depression, burnout, or PTSD as a result of performing your trauma surgery duties with our trauma patient population? If so, please explain the impact it has had on you.

Kyra Nicholson, MD PGY2

Trauma surgery was the second rotation that I had during my intern year. Prior to this rotation I had never seen somebody shot, let alone seen anybody die. I had never heard the words "time of death." Initially, I thought that I would not have the

strength to endure seeing so many patients die and witness the horrific effects of gun violence, but due to the high volume at our institution I find myself becoming numb at times. Moving from one traumatic arrest to the next patient coming in with multiple gunshot wounds begging for you to help save their life. There is not enough time to be human and exhibit emotions. When I reflect on my experience, the times that I felt the most stressed is when I realize that despite saving some of our patients I feel as if we are bandaging them up to only have to return to the same senseless crimes that exist in the South Side of Chicago. I find it disheartening when I do morning rounds and take the time to talk to our patients and some of them see no way out. I find it troubling when I complete a physical examination on a patient and note a previous exploratory laparotomy scar or previous gunshot wound scars. My frustration and depression lie in the fact that despite the long hours that we work, despite working alongside some of the most talented and advanced trauma surgeons in the nation, I at times still feel helpless. I pursued a career in medicine with the hopes of knowing that I am making a difference. The trauma center at the University of Chicago addressed the need for providing emergent medical care to trauma patients in the South Side of Chicago, but I believe we have failed to help stop the catalyst that supplies us these patients. We must help elicit change.

Jelani Williams, MD PGY2R

The first time I probably experienced burnout was in the trauma service. It was February of intern year. It was my seventh week of trauma that academic year—the most at that time for interns. Outside was cold and dark even though I rarely saw it. I had yet to have a break longer than two consecutive days (my first vacation would not come until after this rotation). I found myself more easily agitated. More impatient. I even yelled at an attending in retort for the first and only time. Was it the dreaded intern wall I was hitting? Was it the long Chicago winter? I think taking care of sick and often times dying patients was more of a factor. Taking care of patients who looked like me, who could be my brother, cousin, friend, neighbor. Patients who I felt an unspoken connection with. Taking care of patients who you could sew and patch their injuries but were powerless to fix their circumstances. Powerless to change the environment that would lead some of them to come right back. It was taking care of patients who already arrived dead or died shortly after and just moving on to the next without much processing. I am great at internalizing and moving on. Great at burying stress. However, that month it finally came at a cost. I became cold and dark just like my surroundings. My relationships grew tiring and superficial. My interactions brief. If it were not for some emotional self-awareness who knows where the bottom would fall out.

James Oyeniyi, MD PGY4

It is hard for me to classify what I feel as depression, burnout, or PTSD. Although trauma can be overwhelming, I do my best to separate work from out-of-hospital life so that it does not consume me. With that being said, being at such a high-volume trauma center on the southside of Chicago with a large portion of traumas being violent acts against African Americans like myself, I do have a little anxiety at times when I am leaving the hospital. At times I fear that I may be mistaken for someone

else in the community and that I may become a victim of a violent trauma. I would not say this is debilitating but it does cause me to move with some caution.

2. Do you believe trauma surgeons of color are disproportionally impacted by the stresses resulting from continuous exposure to traumatized individuals?

Kyra Nicholson, MD PGY2

I grew up in the suburbs of Rockville, MD. I grew up in a predominantly white neighborhood. I went to a predominantly white high school and matriculated into college at the University of North Carolina at Chapel Hill. I realize that my upbringing is very different from the trauma patients that we serve. However, what we do have in common is that I was born as an African American female in the United States. Despite our different backgrounds, I still physically look like some of our patients who arrive on stretchers with multiple gunshot or stab wounds. I recall one patient that came in during my intern year, she was a 26-year-old African American female who came in with one gunshot wound to the left lower quadrant. She arrived diaphoretic, hypotensive, tachycardic, and begging for a drink of water. Given that she was unstable we promptly took her to the operating room. She had copious hemoperitoneum upon entering her abdomen. We were unable to identify the site of her injury, but we believed that her iliac artery and iliac vein had been transected. She died on the operating Table. I was tasked with closing her exploratory laparotomy incision. I remember looking at her motionless body and emotionless face. This female looked just like me. African American female in her mid-twenties. I do not know why she got shot, who she was with, what she was doing, but why should this matter? All that matters is that her family will never see her again. Being an African American female surgery resident is stressful within itself because besides having the regular stressors of trying to provide the best medical care I can to my patients, learning and advancing as a surgeon, working long hours, I have the additional stress of feeling like those that work alongside me cannot truly relate to how I feel.

Jelani Williams, MD PGY2R

I grew up in an environment much like that of the South Side of Chicago. Although warmer, with more sunshine and beaches, the US Virgin Islands are plagued with some of the same ills that affect this part of the city; disinvestment and disinterest in communities that lead to higher rates of poverty and inadequate education, the scourge of gun violence, widespread health disparities, and systemic injustices. I have lost classmates, teammates, neighbors, and distant friends to gun violence. I have had to take cover on the basketball court as shots rang out. I have had to offer condolences to friends who lost a loved one. As mentioned above, many times when a trauma patient rolls in I see my friends, I see my family, I even see myself. Again, powerless to stop the vicious cycle that makes trauma centers across the country seem like revolving doors. Often, to protect myself and my emotional well-being, I distance myself from these patients emotionally. And while I have connected with them and even talked down some of them who were filled with anger and frustration, I cannot do this for every patient every time. It becomes too painful, too exhausting,

too familiar. While I cannot speak for every surgeon of color, this is a burden undoubtedly shared by many for those reasons.

James Oyeniyi PGY 4

I do feel trauma surgeons of color are disproportionately impacted by the stress of continuous trauma exposure due to constantly seeing people of color as victims of trauma. I can only speak from my experience but on the southside of Chicago, the overwhelming majority of violent penetrating traumas are against people of color. This forces trauma surgeons of color to see themselves in their patients and feel their pain on a deeper level. It forces them to perhaps see a loved one in their patient and wonder if they are also at risk. This in combination with the current climate in the world toward attacks against people of color from law enforcement and civilians can feel like people of color are being threatened from all fronts which can be a heavy burden to bear.

3. What solutions or recommendations can you offer to improve the resilience of trauma surgeons?

Kyra Nicholson, MD PGY2

Within trauma surgery, we are taught the importance of quickly triaging our patients. Deciding who needs the most immediate medical care. We are taught to be quick and efficient and, in a sense, perfect. There is no room for error in the operating room. What we are not taught is how to effectively deal with our emotions. How should we react when in one trauma shift we lost 5 patients? How should we process having to tell a mother and father that their 25-year-old son was shot and killed and we could not save him? I believe that in order to improve resilience of trauma surgeons we must first change the narrative. Rather than shying away from sharing our emotions and the impact that working with our trauma patients has on us, we must open the room for discussion. If time allows, I think there would be of major benefit in discussing how attendings versus *residents cope with their stress. I think mental health resources such as therapists, mindfulness teaching, and physical activities such as yoga should be provided to residents and attendings. I also think there should be protected time allowing these resources to be utilized appropriately.*

Jelani Williams, MD PGY2R

I think what hurts me the most is my powerlessness to stop the cycle. My powerlessness not to really treat what ills these patients and the public health crisis that affects them. I think many of us became surgeons for some instant gratification and to have a direct impact with regards to healing patients. With trauma and that powerlessness, we are not seeing that gratification. Sure, we stopped the bleeding, reinflated the lungs, and closed the hole in their stomach, but we did not cure the disease. We did not stop its etiology. I say all that to say trauma surgeons and the people involved in taking care of these patients would see improved resilience if we saw that we were making a true difference. Again, we save countless lives in trauma but that hard work day after day is all for naught if we do not have common sense laws that protect our patients and communities. It means nothing if we don't see decreases in recidivism and the holistic improvement of the communities of our

patients. It goes in vain if we cannot counter the lobbies and harmful ideologies that fight against our work. Cancer surgeons can often cure cancer and bariatric surgeons can cure obesity and diabetes. Can trauma surgeons cure gun violence? I think we need to keep trying.

James Oyeniyi PGY 4

Every person is different and handles their stressors differently. It is important to provide resources such as mental health therapists, spiritual leaders, and peers to allow a means to discuss emotions and thoughts around the trauma being observed. Just as important is also providing the protected time for surgeons to actually utilize these resources. Too often these resources are flaunted but there is no reasonable time to actually utilize them. This is not something that should be pushed on surgeons but should be available if they are desired. Besides that, ensuring that surgeons have adequate time to spend with family and friends, engage in hobbies, work out, and enjoy other wellness activities allows an escape from the emotional trauma.

Our summary of recommendations is presented in Table 33.2.

Table 33.2 Summary of recommendations

Driver	Individual-level solutions	Institutional-level solutions	Societal-level solutions
Sleep deprivation	Practice proper sleep hygiene habits and when possible prioritize 8 hours of sleep per night	Monitoring and adjusting work schedules and abide by work hour restrictions	Organize for workers' rights, and unionization to protect adequate leisure time for workers
Poor nutritional and health habits	Drink water, choose healthy food options when available, exercise daily	Provide access to healthy food 24/7 Incorporate exercise into call schedules	Heavy taxation on fast foods; making fresh produce more accessible and socially appealing; strengthening green modes of transportation and making gyms accessible to all
Emotional and psychological distress	Engagement in physician small-group activities around shared work experiences	Provide a safe, organized and confidential space to debrief following an adverse event	Combat structural violence to ensure that we are not "normalizing the abnormal," such as young men dying of gun violence
	Use of therapists, positive coping mechanisms	Create a trusted and confidential system for reporting and providing mental health treatment for medical professionals	Remove all taboos regarding mental health and normalize prevention within a framework of universal health care

(continued)

Table 33.2 (continued)

Driver	Individual-level solutions	Institutional-level solutions	Societal-level solutions
Loss of meaning from work	Reflection of most fulfilling patient encounters	Promote shared core values	Ensure elected officials reflect the shared core values of the majority
	Spend time with friends and family, celebrate accomplishments	Show gratitude for hard work and successes, both personal and academic of attendings and trainees on a routine basis	Place societal value on nonmaterial, nonprofit generating contributions such as for healthcare workers during COVID-19 pandemic, celebrate science to guide national and global decision-making
	Stay abreast of societal level trauma	Align decisions and actions with a meaningful mission	Societal recognition of surgeons and trainees as activists or advocates for systems-level change
	Attention to self-care	Provide weekly assessment of burnout for attendings and residents via the ACS	Attention to systems-level causes of burnout of entire professions by surgical leadership organizations such as the ACS
	Practice mindfulness, other meditation practices, or religious practices	Develop institution-wide educational programs about physician wellness	Address the root cause of societal burnout upstream and compare with other countries or historic precedents for mitigation

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Youth Violence Prevention: Violence Recovery Programs

34

Omar K. Danner, Richard Sola, Caroline Butler, and Klahe Butty

Introduction

Violence is a major cause of fatal and non-fatal injury among youth in urban communities. The current challenge is identifying evidence-based violence prevention and recovery programs that are effective in mitigating violence related harm against youth and young adults. Few published studies have clearly defined what constitutes the "best practice components" for guidance of policy and development of a sustainable, effective prevention program. The aim of this review is to analyze the structure and characteristics of successful youth violence and injury prevention programs (YVIPPs) and define which aspects of existing programs represent the best practice components for potential widespread replication.

This review will evaluate existing YVIPPs, particularly in urban areas, to identify best practice components. Additionally, this analysis will identify, explore, and dissect community-initiated interventions that have successfully contributed to a reduction in youth violence. Together, the identified best practice components for YVIPPs will serve to address the issue of youth violence reduction in urban localities and provide cost-effective alternatives to implement youth violence prevention

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and recovery programs. These recognized best practice components may then serve as recommended elements for inclusion in the fundamental principles for effective YVIPP strategies. Adoption of these best practice components could lead to approaches that will help break the cycle of youth violence. The significance of this review is that it will summarize the trauma and public health literature on youth violence prevention by identifying and categorizing best practice components for both hospital-based and community-originated violence interventions. This will give current and future researchers and practitioners information on how, in combination, these two approaches can reduce youth violence.

Search Strategy

In order to compile this in-depth analysis, current and former YVIPPs from 2000 were systematically reviewed using 7 scholarly databases, including Cochrane, Ovid, PubMed, and others. English language studies and similar reports targeting urban American youth principally aged 10–25 were included for this exploration. Using common program evaluation techniques, the programmatic elements were critiqued and deemed a best practice component if they were observed in greater than or equal to 80% of programs assessed. The literature was also evaluated to identify and distinguish community-initiated versus hospital-based interventions. Fifty-five abstracts were initially screened, and a total of eight programs were classified as community-initiated violence and injury intervention and prevention initiatives. These types of program are focused on in this review as violence recovery and healing are best carried out in the community. Nationwide, seven out of eight programs (87.5%) demonstrated the use of community outreach workers (COWs) as a best practice component, especially in urban-centric youth violence prevention programs. Our review of YVIPPs support the use of culturally competent COWs as a crucial component for successful YVIPPs, particularly in urban settings. This review will discuss in detail effective community-originated interventions and their role in preventing youth violence. The Butty Socioecological Model for YVIPP (Fig. 34.1) will also be discussed as it provides a conceptual framework to help guide communities in addressing and decreasing youth violence**.**

Due to the broad nature of the topic of violence, various scholarly search engines and databases were accessed in order to identify programs. Reports and peer reviewed journal articles were identified through search engines and databases such as ERIC, Wiley, Google scholar, Science Direct, Galileo, Springer Link, and PubMed. Table 34.1 shows a brief description of the methodology used for the *Systematic Review of Youth Violence Prevention Programs Nationwide to Identify Best Practice Components,* which included the following steps:

1. Define guidelines to evaluate at least 50 youth violence prevention programs identified online from websites and electronic research databases from 2000–2015.
2. Identify the criteria for including and excluding youth violence prevention programs.

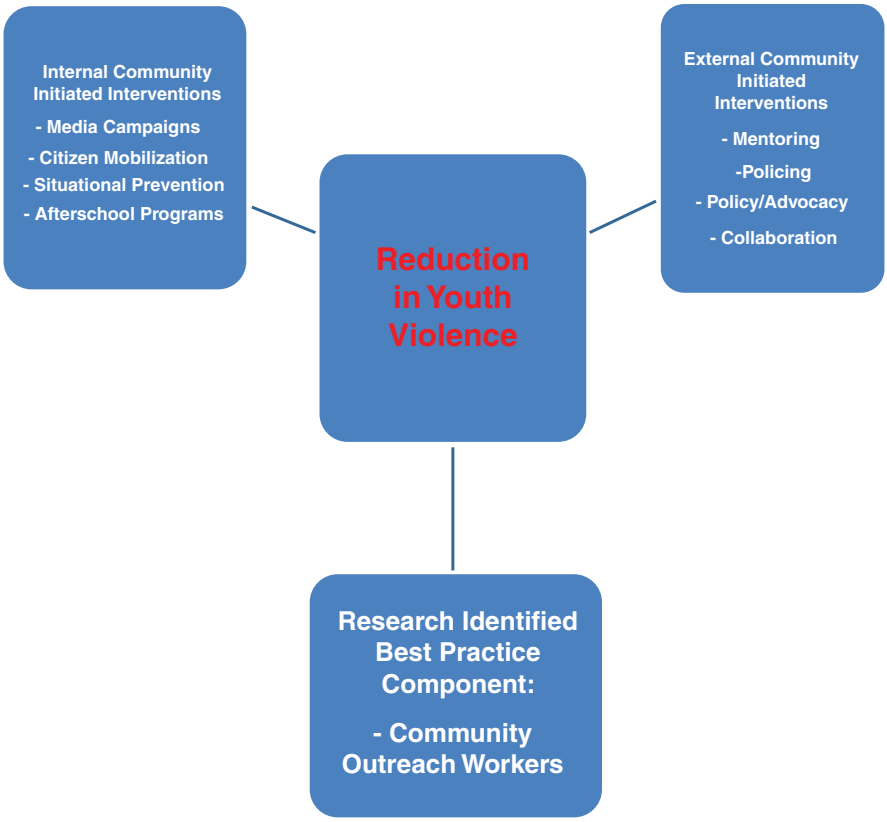

Fig. 34.1 Butty's conceptual framework for internal and external community-initiated interventions combined with identified best practice component

Table 34.1 PICO table showing a brief description of the methodology used for the *systematic review of youth violence prevention programs nationwide to identify best practice components*

Patients	Intervention	Comparator	Outcomes
Adolescents and young adults at risk for violence	Violence prevention and recovery programs	Citizen mobilization, mentoring, situational awareness, policing, policy changes	Reduction in rates of youth violence and recidivism

3. Develop the criteria and procedures for the search.
4. Retrieve and review the youth violence prevention programs.
5. Assess the quality of the components of the YVIPPS programs based on the guidelines.
6. Summarize the findings for each youth violence prevention program.
7. Identify and summarize the commonalities and differences for the youth violence prevention programs.
8. Identify and summarize limitations of the youth violence prevention programs.
9. Develop implications based on the findings and limitations.

The Results

The path that leads young people to either commit or refrain from acts of violence is complex and comprised of a multitude of influences referred to as risk and protective factors. Risk factors are any condition or variable that will increase the likelihood of harm. These factors do not directly cause violence; however, they are contributors to violence. On the other hand, protective factors are any condition or variable that will decrease the potential of harm. Both factors are of importance when studying youth violence as they serve as indicators for violent activity. Risk and protective factors exist at various levels that correspond with that of the social-ecological model. These factors are of importance when discussing the prevention of violence as they serve as guides for violence prevention program development. Risk factors that can contribute to the complex nature of youth violence fall within categories such as individual, biological, community, and interpersonal. Risk factors can express themselves as alcohol and substance abuse, negative peer influences, economic factors, educational attainment, and prior history of violent victimization. No risk factor works in complete solitude, as the aggregate exposure by youth to various risk factors increases their likelihood of perpetrating violent activity [1]. Like risk factors, protective factors fall within the four categories. Protective factors include religiosity, involvement in social activities, positive interaction with parents, and high IQ. Aggregate exposure to protective factors helps to shield youth from the risks of becoming violent.

In order to prevent violence, it is important to understand the many factors that contribute to violence. Violence is described as the result of a confluence of individual, relationship, social, cultural, and environmental factors (WHO, 2014) [2]. Therefore, focus should be placed on understanding each factor individually as well as their coexistence and interaction in designing interventions and programs for youth violence prevention. The social-ecological model (SEM) is well suited for addressing this topic as it can be used to view the issue of violence through a multifocal lens (see Fig. 34.2). SEM was developed by American developmental psychologist, Urie Bronfenbrenner. This model has roots in youth violence prevention efforts as it was first introduced in the 1970s for a child abuse study (World Health Organization, 2002) [3]. In the following years this model was applied to other studies of violence. Much of Bronfenbrenner's work in the field of violence represented the culmination and synthesis of various multidisciplinary empirical studies (Gauvain & Cole, 1993) [4].

Violence is a learned behavior. As such, Bronfenbrenner's model focuses on the human development pathway as it relates to violence. These layers include the individual, relationship, community, and societal. The nested constructs of the social-ecological model explain the interrelated factors that place people at increased risk for violence (risk factors) and protect them (protective factors). The ecological model is a useful tool as it aids in distinguishing between the various influences of violence and provides a framework for understanding how these influences interact. Existing violence prevention programs target various levels such as the individual, relationship, community, and societal. Thus, the ecological model can be used as

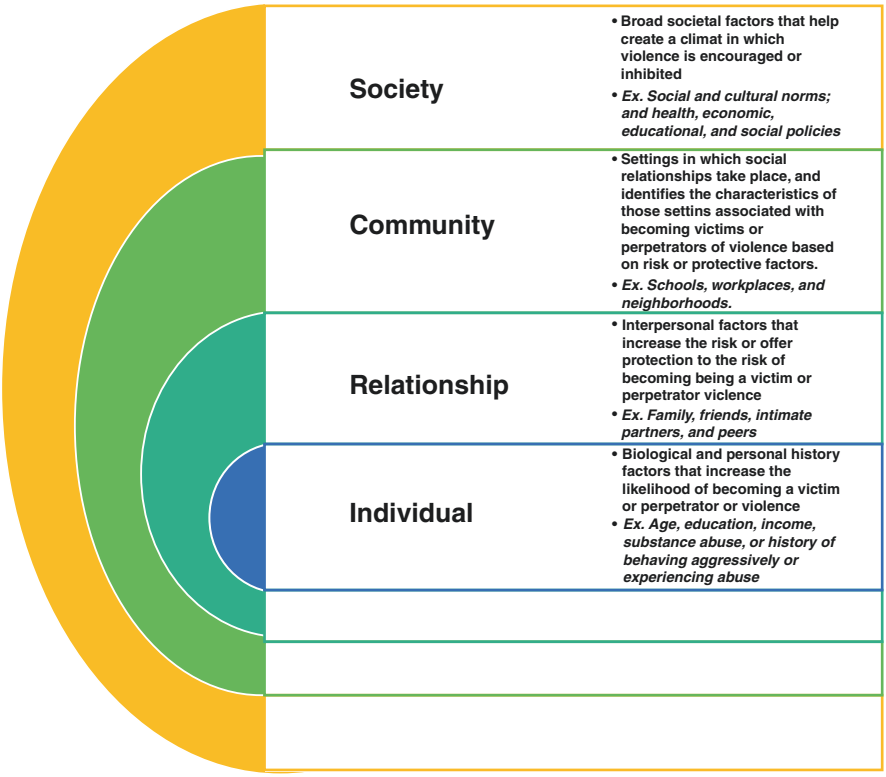

Fig. 34.2 The social-ecological model by Urie Bronfenbrenner. The results of the systematic literature review produced eight articles on youth violence prevention programs in urban areas nationwide to identify best practice program (see Fig. 34.3). These programs included full program and/or evaluation reports

evaluative criteria for programs and interventions and for sorting them into their corresponding levels. Bronfenbrenner's model puts the issue of violence in context as it emphasizes the influence of external factors on individual behavior. Through understanding the different contexts of violence, the use of SEM can help to coordinate and integrate the varous components needed for successful violence prevention strategies. Table 34.2 provides a brief summary of characteristics of Current and Former Successful Youth Violence Prevention Programs along with a d*escription of Intervention Type and Intervention Strategy for Selected Violence Prevention Programs.*

According to Catalano, Loeber & McKinney [5] there are 8 types of community-initiated interventions including citizen mobilization, situational prevention, comprehensive community interventions, mentoring, afterschool recreational programs, policing strategies, policy change, and media interventions. The early work of Shaw and McKay in 1942 speculated that certain community characteristics led to community disorganization, or the inability of communities to maintain social control,

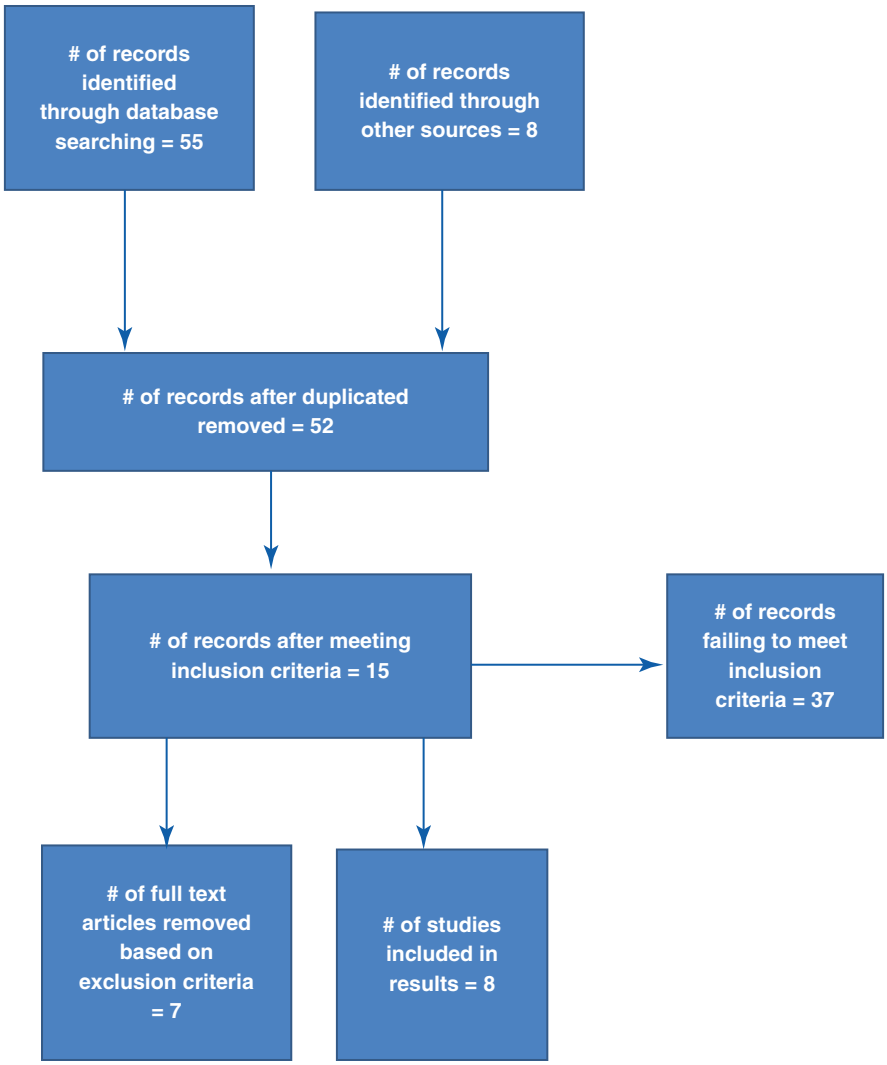

Fig. 34.3 Consort diagram of articles and publications

thereby leading to high delinquency rates [6]. In the 1970s and 1980s, the concept of social disorganization was defined explicitly as "the lack of ability of a community structure to realize the common values of its residents and to maintain effective social controls, such as to prevent violence" [7–9]. In this "systemic view," the local community is characterized by complex systems of friendship, kinship, and acquaintanceship networks and by social ties rooted in family life and ongoing socialization processes that give rise to social cohesion [10, 11]. This view suggests that networks of strong personal ties within communities are primarily responsible for community capacity to prevent violence.

Table 34.2 Summary of characteristics of current and former successful youth violence preventions programs

	Program name	City	Age	Form of violence	Intervention type	Intervention strategy
1	Caught in the crossfire	Oakland, CA	12–20	Non-fatal injury	Hospital-based peer intervention	Crisis intervention specialist
2	One vision one life	Pittsburgh, PA	18+	Homicide, aggravated assaults, and gun assaults	Community-based	Conflict intervention (street workers)
3	Operation ceasefire	Chicago, IL	16–25	Gun violence	Community-based intervention	Violence interrupters
4	Operation peacekeeper	Stockton, CA	10–18	Gang homicide	Community-based	Outreach workers
5	Operation peace works	Ventura County, CA	13–24	Gang violence	Community-based	Street outreach
6	Safe streets	Baltimore, MD	18–24	Homicide and non-fatal shootings	Community-based	Conflict mediation
7	Save our streets	Crown Heights, NY	16–25	Gun violence	Community-based intervention	Outreach and conflict mediation
8	Project Ujima	Milwaukee	10–18	Interpersonal violent injury	Community-based violence intervention/ prevention program	Home visitation

It also provides a brief description of intervention type and intervention strategy for selected violence prevention programs

Findings of the systematic review of best practice components of YVIPPs revealed several consistent program components for effective violence prevention programs for urban American communities Table 34.3 shows a brief description of the eight best practice programs selected from the systematic review (see Table 34.3). Program components were deemed as "best practices" if they were observed in 80% or more of the identified programs. Eighty percent was designated as an acceptable criterion for assessing best practice components as deemed by the researchers. Identifying these program elements is important in finding out "what works" in the field of youth violence prevention. These program elements have demonstrated effectiveness due to repeated observations in various programs nationwide.

In this review, the community outreach worker component was a demonstrated best practice component as it was observed in seven of eight (or about 88%) programs. Table 34.4 shows a description of the number and percentage of best practice components. Thus, this program element contributes to program success and

Table 34.3 Number and frequency of components identified in eight youth violence prevention programs

	Component	No. of programs	Frequency (%)
1	Street outreach workers	7	88
2	Case management	4	50
3	Public education	2	25
4	Faith-based leader involvement	2	25
5	Community mobilization	2	25
6	Criminal justice participation	2	25
7	Mentoring	2	25
8	Home visitation (community liaison)	1	12
9	Call-ins	1	12
10	Community advocacy	1	12

effectiveness as it meets the specified observation criteria. The majority of the urban communities in this study demonstrate the use of this viable youth violence prevention practice component. Second to community outreach workers, case management is observed to be a component found in a significant number of programs. Though not fitting the criteria of a best practice component, this program element is observed in four of eight (approximately 50%) identified youth violence prevention programs in the study.

Following case management were components such as public education, faith-based leader involvement, community mobilization, criminal justice participation, and mentoring, which were each observed in two of eight (25%) youth violence prevention programs in the study. The remaining components, home visitation, call-ins, and community advocacy were each found in one of eight (12%) youth violence prevention programs in this study. These programs did not fit the criteria for a best practice component because they were not observed in over 80% of the eight selected programs in this study. While several components did not meet the research requirement of 80% to be considered a best practice component it must be recognized that community characteristics, the degree of youth violence in a city, and program goals will require programs to consider different approaches.

Findings from the literature review revealed eight main types of community-originated interventions that communities engage in to mitigate and recover from youth violence. These approaches include (1) citizen mobilization, (2) situational prevention, (3) mentoring, (4) afterschool recreation programs, (5) policing strategies, (6) policy changes, (7) media interventions, and (8) comprehensive community interventions [5].

Broadly, mentoring could be described as guidance from positive role models to prevent violence. In other words, mentoring programs are programs in which adult mentors spend time with and act as positive role models for individual youth. According to Catalano, Loeber, and McKinney [5], community-initiated mentoring programs address several risk factors (i.e., academic failure and alienation), while introducing protective factors (i.e., opportunities for pro-social involvement and clear standards for behavior). Research has found mentoring to be a common

Table 34.4 Community-initiated interventions effectiveness rating

	Community-initiated intervention	Program/Practice	Description	Effective	Promising
1.	*Citizen mobilization*	Neighborhood watch	Neighborhood watch programs involve citizens in efforts to prevent crime in their neighborhood or community		
2.	*Mentoring*	Big brothers big sisters (BBBS) community-based mentoring (CBM) program	Offers one-to-one mentoring in a community setting for at-risk youth between the ages of 6 and 18.		
3.	*Situational prevention*	Street lighting in stoke-on-Trent	A program that upgrades street lighting on residential roads and footpaths to decrease crime and fear of crime.		
4.	*Afterschool recreation programs*	Success for kids (SFK)	An afterschool program that sought to build resilience in children by teaching them to access inner resources and build positive connections with others.		
5.	*Policy changes*	Reducing gun violence	To reduce gun violence, several strategies have been deployed including public health approaches (e.g., training and safe gun storage); gun buy-back programs; gun laws; and law enforcement strategies.		
6.	*Policing strategies*	Problem-oriented policing (POP)	An analytic method used by police to develop strategies that prevent and reduce crime		
7.	*Media interventions*	Peace Builders	A school-based violence prevention program designed to reduce aggression and improve social competence		
8.	*Comprehensive community interventions*	Operation ceasefire	A problem-solving police strategy that seeks to reduce gang violence, illegal gun possession, and gun violence in communities in Boston, Mass.		

approach used by communities to prevent and heal youth violence [12]. According to Catalano, Loeber & McKinney [5], evidence from 10 evaluations of mentoring programs consistently indicate that non-contingent, supportive mentoring relationships have not had the desired effect on various aspects of child behavior (including misconduct). One of the most popular community-based mentorship programs is that of Big Brothers Big Sisters (BBBS) [13]. This program generally targets youth aged 6–18 and involves one on one mentoring in a community setting. According to results from the Tierney, Grossman, and Resch [14] in a study on the effects of BBBS mentorship and youth antisocial behavior outcomes, youth mentored through BBBS were 32 percent less likely to have struck someone during the previous 12 months compared with the control group.

In general, comprehensive community interventions call for carrying out a coordinated set of preventive interventions throughout communities [15]. Comprehensive community-originated interventions were observed in various violence prevention programs referenced in this study. For example, Operation Ceasefire combined law enforcement and community mobilization components in its tactic against youth violence. The comprehensive community-initiated intervention approach addresses multiple risk factors in the community, schools, family, and the media by mounting a coordinated set of mutually reinforcing preventive interventions throughout the community. Thus, collaboration is critical as the issue of youth violence is dispersed among various disciplines and communities should plan to collaborate with pertinent stakeholders to address issues related to youth violence.

Recommendations Based on the Data

For successful youth violence and recovery programs, community outreach workers have been demonstrated as a best practice and should be included as an essential component of new programs. Without an established connection to the community, it is difficult for YVIPPs to effect change and bring about recovery after episodes of violence. In addition to community outreach workers, culturally competent case management is another valuable component for efficacious interventions and should also be considered a significant asset for prototypical programs. The majority of the urban communities in this study demonstrated the use of one or both of these viable youth violence prevention practice components. The focus of the program staff should be on reducing some of the major risk factors, including easy access to firearms and drugs, community disorganization, and community norms or attitudes favoring antisocial behavior while augmenting protective factors, such as social bonding and clear community norms against antisocial behavior. Broadly speaking, mentoring should be used as an adjunct to other program interventions as evidence from 10 evaluations of mentoring programs consistently indicate that non-contingent, supportive mentoring relationships have not had the desired effect on various aspects of child behavior (including misconduct). Community advocacy is an important ingredient as it can draw attention to an issue while it produces change. Advocacy can be used to draw support for communities on many issues including

youth violence. Additionally, policy change focused interventions that involve strategic decision-making to influence regulations and laws against violence should be incorporated into the overall violence prevention and recovery strategy. Laws regulating the access to firearms have been shown to provide some positive effects. Policy changes can help promote protective factors and substantially reduce risk factors for youth violence. Finally, violence recovery programs should work collaboratively with communities and their leaders to help in the development of interventions to prevent or reduce youth violence. Collaboration is critical as the issue of youth violence is dispersed among various disciplines. Thus, communities should plan to collaborate with pertinent stakeholders to address issues related to youth violence. Collaboration between communities and other stakeholders can address the many risk factors that influence violence within and outside the immediate boundaries of a community.

Summary of Recommendations

- Community outreach workers have been demonstrated as a best practice and should be included as an essential component of new programs (evidence quality moderate; strong recommendation).
- Without an established connection to the community, it is difficult for YVIPPs to effect change and bring about recovery after episodes of violence (evidence quality moderate; strong recommendation).

A Personal View of the Data

There are several limitations to creating and implementing effective youth violence prevention and recovery program that should be considered. First, violence prevention practitioners must realize that identified best practices have different outcomes based on context. There is no "one size fits all" as it relates to youth violence prevention components. Therefore, as the context of violence differs depending on the community, including SES and demographic settings, the recommended best practice components and proposed community-derived interventions may not be applicable to or reliable in all communities. Another principle limitation of this review is the limited amount of quality literature available for systematic review. Although the literature on youth violence programs is growing due to its cross disciplinary nature, a larger number of specific articles would have helped to strengthen the validity and generalizability of the supporting data and made it a better representation of program components in the field of violence prevention. Future violence prevention research should focus on exploring other protective community characteristics in relation to YVIPPs. Exploration of these characteristics will help to better target effective interventions to support the community's needs. In the end, youth violence can be reduced when responsible individuals implement comprehensive strategies to eliminate complex societal issues and challenges.

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Part IX

Peripheral Vascular Trauma

Are Temporary Vascular Shunts (TVS) Effective Damage Control Adjuncts for Limb Salvage?

35

David Hampton and Kenneth Wilson

Introduction

During World War I, it was concluded that extremity vascular repair was unwise under combat conditions, despite the dawn of reverse saphenous vein grafting (RSVG) [1]. This belief was held in part by new wounding patterns from the machine gun, prolonged ischemia times due to trench warfare, and due to wound contamination resulting in secondary hemorrhage. Debakey's and Simeone's classic report of common femoral and iliac artery ligation in World War II resulted in amputation rates of 53.8% and 46.7%, respectively [2]. Debakey conceded that RSVG was impractical for similar reasons as concluded during WWI, and that ligation is not the treatment of choice for injured arteries, but a necessity. The Vietnam War ushered in the modern era of war time treatment for extremity vascular injuries. The expeditious evacuations, and effective resuscitations taking place adjacent to the battlefront by forward Surgical Teams (FSTs) reduced the lag time between ischemia and definitive repair, dropping the amputation rate to approximately 8% during the Vietnam War [3–5]. In recent reviews of the military conflicts in both Afghanistan and Iraq, it is estimated that vascular injuries account for roughly 4.4–7.1% of all injuries, of which extremity vascular injuries account for 70–75% [6]. The current projection is that the rate of extremity vascular injury will be three to five times that reported from previous wars [7].

Lessons learned from earlier military conflicts is to avoid amputations after tenuous RSVG in the presence of complex wounds, and to quickly restore perfusion with temporary vascular shunts (TVS) until definitive repair can be accomplished [8]. TVS as damage control adjuncts have been used up to 25% of extremity

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vascular injuries treated in Iraq, and are currently mandated by military clinical practice guidelines (CPGs) in both theaters of operations in Iraq and Afghanistan. Definitive arterial repair, as outlined in the CPG, can be delayed with TVS in place until a facility with increased vascular capabilities is reached (Role-3) [9].

Data supporting TVS use in civilian trauma have been extrapolated mostly from the military. As opposed to the military vascular trauma systems, civilian trauma centers encounter patients with mostly blunt mechanisms arriving primarily to a well-equipped trauma hospitals where TVS utilization is infrequent. The current clinical questions is to ascertain whether or not TVS shunts are effective extremity damage control adjuncts for limb preservation, and do TVS decrease the primary and secondary amputation rates for trauma patients sustaining vascular injuries in military and civilian settings.

Search Strategy

We performed a systematic literature search indexed by the MEDLINE database. The MEDLINE database was queried with the PubMed search engine. We employed the terms: "extremity injury, penetrating, vascular, tourniquet, military trauma, civilian trauma, vascular shunt, vascular surgery, amputation, and mortality." The literature search was limited to peer-reviewed articles published in English language journals. Given the historical breath of trauma and the military's usage of TVS, we did not impose a date range limitation in our search. All articles were reviewed by the authors and selected for inclusion based upon our PICO criteria (See Table 35.1).

Results

Is It Safe to Deploy TVS in a Far-Forward Setting?

TVS as extremity damage control adjuncts have been reported anecdotally as case series lacking rigorous statistical scrutiny as is the situation for most war-related interventions. The majority of the reporting of early efficacy of TVS originated

Table 35.1 PICO table

Patients	Intervention	Comparator	Outcomes
(a) Military extremity vascular injuries. (b) Civilian vascular injuries. (c) Concomitant vascular/bony injuries.	Temporary vascular shunts (TVS)	(a) TVS placement. (b) Definitive arterial repair. (c) Orthopedic fixation("unstable fracture") before TVS. (d) TVS before orthopedic fixation ("unstable fracture").	(a) Limb salvage. (b) Amputation rates. (c) Fasciotomies. (d) Compartment syndrome. (e) Graft failure. (f) Mortality.

from Forward Surgical Teams and the 332nd Expeditionary Medical Group (EMDG) in Iraq during Operation Iraqi Freedom (OIF). Rasmussen et al. reviewed their experience with 30 TVSs during a 1-year deployment at the EMDG in Balad, Iraq (Role-3) [10]. Twenty-eight of the thirty shunts were placed by FSTs (Role 2) before evacuation to the EMDG at Balad Air Base. All of the shunted extremity vascular injuries were reconstructed at the Role-3 and had an early viability rate of 92% elucidating TVS as safe and effective damage control adjuncts in austere environments. Taller et al. identified 23 proximal shunts placed in 16 patients [11]. Twenty-two (95.6%) TVS were patent upon arrival to the Role-3 facility and underwent successful autologous reverse saphenous reconstruction. All TVS patients survived their injuries with early 100% limb preservation. Chambers et al., retrospectively reviewed their operative experience during the early phases of OIF while also stationed at Balad [12]. There were 223 patients that required 409 extremity operations with 66 (23%) sustaining injury to named vessels. Twenty-seven TVS were used to bypass complex vascular injuries in 20 combat casualties with a mean ISS of 18 (inter-quartile range (IQR): 9–34) and a mean mangled extremity score of 9 (IQR: 6–11). All patients ultimately survived with only 3 requiring amputations. Two of the three reported amputations occurred after shunting the posterior tibial arteries. Subsequent studies have shown that TVSs are more likely to fail if utilized below the knee. The absence of mortality without major bleeding complications alongside their 85% limb salvage (with no limbs being lost secondary to ischemic complications) further supports the relative low risk of placing TVS by FSTs. Kauvar et al. queried the Fasciotomy and Vascular Injury Outcomes (FaVIO) database of warfighters who sustained femoropopliteal injuries from the Iraq and Afghanistan theaters of operation [13]. All of the injured soldiers in the study were evacuated to Landstuhl Germany (Role-4). Two hundred and fifty-seven cases were identified, and 46 of the femoropopliteal injuries (18%) were shunted at FSTs (R2SHUNT) locations in Iraq and Afghanistan. R2SHUNT patients had a median extremity Abbreviated Injury Scale of 4 (other groups, 3; $p < 0.05$), and were more likely to have a concomitant venous injury and to undergo fasciotomy. If a thrombosis occurred, it was more common in R2SHUNT patients requiring revision of the shunt. However, despite thrombosis of the TVS, the failures did not lead to limb loss. The authors concluded that staging femoropopliteal bypasses with TVS at a Role-2 austere location was associated with similar limbs salvage rates as compared to TVS placement at Role-3 facilities.

TVS and Military Amputation Rates

Hasde et al. performed a retrospective study evaluating 96 cases of war-related lower extremity arterial injuries subdivided into two broad groups, TVS group (TVS group, $n = 24$) vs. non-TVS group (non-TVS group, $n = 72$) [14]. In comparing the two groups, there were 18 amputations [TVS group = 1 (4%); non-TVS group, $n = 17(24\%)$]. In their small series, the authors concluded that the use TVS may serve as a bridge between initial injury and definitive repair with a reduction in

amputation rates. Borut et al. examined combat soldiers who sustained extremity vascular injuries between July 2003 and May 2007 during the Iraq and Afghanistan conflicts with a 2-year follow-up [15]. There were 80 patients included in the study, and 46 (57%) had TVS placed and 34 (43%) underwent immediate repair at initial presentation. There were no reported differences in the amputation rates between the two groups (16%).

Gifford et al. performed the most comprehensive review of the utility of TVS as a damage control adjunct for limb salvage [16]. The retrospective study was a direct comparison of patients with TVS to a control group with similar injury dates and anatomic locations managed without TVS. The Joint Theater Trauma Registry (JTTR), the Balad Vascular Registry (BVR), and the Walter Reed Vascular Registry (WRVR) were all queried. Electronic medical records and patient interviews on American Troops sustaining extremity vascular injury from June 2003 to December 2007 were also collected. The TVS group was more severely injured (mean ISS-18 vs ISS-15) and more likely to receive Role-2 care (26% vs. 10%). A suggested benefit of TVS was found, but did not reach statistical significance. Amputation-free survival was 78% in the TVS group and 77% in the control group at three years. The authors flatly concluded that TVS used as a damage control adjunct in the management of wartime extremity vascular injury does not lead to worse outcomes. Despite not reaching statistical significance for decreasing amputation rates in the Gifford study, the high limb salvage rate and ease of TVS placement demonstrated by other military vascular studies make TVS a strong consideration when limb viability is a concern [17].

Blast Injuries Amputation Rates

Military experiences suggest that patients who have sustained their injuries through explosive mechanisms rather than by lower kinetic penetrating mechanisms tend to have earlier TVS and graft failure rates despite similar injury severity scores. A British review from the UK Joint Theatre Trauma Registry concluded that over 80% of the injuries sustained by UK and USA service personnel were in an extremity [18]. Over 70% of these injuries were as a result of a blast mechanism. The thrombosis rate was three times higher and amputation rates two times higher for blast related injuries. The unilateral use of IEDs on the battlefield resulted in more mangled extremities increasing amputation rates. In another British Study, injuries by explosions ($n = 416$) had more tibial and popliteal injuries and required more blood products as compared to the firearm group ($n = 181$) that had more proximal injuries [19]. The explosion group unsurprisingly had higher ISS, Mangled Extremity Scores (MESS), and increased amputation rates as well.

TVS in the Civilian Setting

The pre-hospital application of tourniquets has been readily adopted into civilian practice as a tenet of extremity damage control as outlined by Tactical Combat

Casualty Care (TCCC) [20]. However, the incorporation of TVS in civilian practice has not been fully embraced. Data supporting TVS use in civilian trauma have been imported mostly from military experiences. However, civilian trauma is mostly blunt, and when penetrating, the low kinetic energy wounding from handguns in civilian trauma is barely comparable to the military experience. A large multicenter study revealed that TVS are infrequently used for vascular injuries, with only 213 TVS placed for 7385 patients (2.7% of vascular injuries) over 9 years [21]. TVS were required for damage control cases in 63.4% of the patients. Combined vascular-orthopedic repair was performed in 36.1% of the cases. The superficial femoral artery was most commonly shunted (23.9%) followed by the popliteal artery (18.8%). The authors reported a low complication rate: shunt thrombosis (5.6%) and dislodgement (1.4%). A National Trauma Data Base analysis (NTDB) demonstrated that when TVS are considered, 74% are placed in blunt trauma patients with a combined vascular-orthopedic injury [22]. The most shunted extremity vessels were again the superficial femoral artery followed by the popliteal artery. Hossny et al. retrospectively reviewed 17 patients that all sustained blunt popliteal injuries [23]. Shunting was shown to reduce ischemia time, fasciotomies, and amputation rates as compared to non-shunted groups. The restoration of blood flow through TVS is advised in the presence of concomitant unstable bone and vascular injuries while immediate vascular repair is advised for "stable skeletal injuries." [24]

Civilian Amputation Rates

Rayamajhi et al. performed a single center study of a busy urban trauma center within Cape Town, South Africa [25]. Their 10-year retrospective review identified 158 patients with femoral artery injuries. Eighty one of these injuries were primarily repaired. Twelve had TVS placed, of which four ultimately had a limb amputations. The authors found primary and secondary amputation rates of 2.5% and 6.5% respectively. Wlodarczyk et al. performed a 10-year retrospective review of six Level-1 trauma centers' experience with TVS for combined vascular and orthopedic extremity injuries [26]. They identified 291 patients of which, 72 had TVS placed, 97 underwent initial definitive vascular repair, and 122 had an orthopedic fixation ahead of vascular considerations. Those initially shunted had a higher Abbreviated Injury Severity Scale (3.0 vs. 2.8, $p = 0.04$) and MESS (6.1 vs. 5.7, $p = 0.006$). The shunted patients were also associated with significantly lower compartment syndrome rates (15% vs. 34%, $p = 0.002$). Those undergoing initial orthopedic fixation experienced longer lengths of stay (>15 days, 61% vs. 38%; $p = 0.049$) and higher amputation rates (20% vs. 7%, $p = 0.006$). The most recent study of TVS identified 78 patients from 24 trauma centers that after propensity matching, control patients had a three times greater likelihood of amputation compared to TVS patients (odds ratio: 3.6; 95% CI: 1.2–11.1; $p = 0.026$) [27]. TVS were shown to expedite limb perfusion and result in lower rates of amputation during the early phase of care.

Penetrating Civilian Trauma

Trauma to the common or external iliac arteries has a mortality rate of 24–60%, respectively. Previous "damage control" options for these severely injured patients were mostly limited to ligation, which was associated with a 50% amputation rate. Ball et al. reviewed 88 patients with iliac artery injuries who underwent ligation versus those receiving TVS placement [28]. Compared with patients who underwent ligation, TVS patients received fewer amputations (47% vs. 0%) and had an improved mortality rate (43% vs. 73%). In a study by Oliver et al., they reviewed their 9-year experience with iliac vessel injuries [29]. Sixty-nine patients sustained 59 gunshot wounds resulting in 108 iliac vessel injuries. Ten patients underwent primary repair of the common or external iliac arteries. Six patients had TVS placed with delayed graft repair. TVS placement for unstable patients was found to be an appropriate intervention, allowing surgeons and intensivists time to address other injuries and metabolic derangements prior to a definitive repair.

In patients presenting with multi-system injuries, the sequence of operative interventions can greatly influence the ischemic time, limb salvage, and mortality. McHenry's group reviewed the implications of surgical sequence over a 10-year period [30]. The review included 27 patients who presented with upper and lower extremity injuries secondary to gunshot wounds. Fracture fixation preceded vascular repair in 5 cases, whereas revascularization preceded bone fixation in 22 cases. A temporary vascular shunt was used in 13 cases, and definitive vascular repair was used in 9 patients. There were no cases of vascular repair, shunt disruption, or amputation after fracture fixation. On the basis of the study, the authors recommend that priority should be given to revascularization before orthopedic fixation because of shorter hospitalization and a trend toward lower fasciotomy rates.

Mangled Extremity

Mangled extremity vascular injuries often present with irreversible ischemia. The potential for an attempt at limb salvage is predicated upon flow restoration, which can be provided by a TVS. Sriussadaporn's group reviewed their 4-year institutional experience with mangled extremities arriving from austere conditions [31]. This review performed in Bangkok, Thailand, used simple polyethylene intravenous and extension tubing as a conduit demonstrating the practicality of common equipment being used for intraluminal shunting. The pre-operative times ranged from 120 to 450 min with the TVS inserted within 30 min of the initial operation. All shunts were removed during the index case and all limbs were successfully salvaged. The Western Trauma Association guidelines for the management of the mangled extremity recommend TVS as a temporizing measure to restore distal perfusion while the remainder of the evaluation is being conducted or during bony evaluation/fixation [32]. The authors' experiences with mangled extremities are that TVS allows for multidisciplinary

conversations about limb salvage, allowing other surgical services a moment to gain understanding of patient wishes without having to proceed immediately to amputation.

Timing of TVS Placement

Gifford et al. created the first laboratory model to demonstrate that the early application of TVS within 1 h of extremity ischemia results in decreased measures of injury as compared to delayed shunt placement [33]. A porcine hind-limb ischemia model via iliac artery occlusion was used to ascertain flow differences and circulatory markers of ischemia with "early vs. late" TVS placement. The control group underwent iliac artery exposure with no occlusion and without TVS placement, while four groups underwent iliac occlusion at increasing increments of time at 0, 1, 3, and 6 h. After each interval of warm ischemia, hind-limb perfusion was established using a TVS. Limb perfusion was performed for 18 h. The findings included primary patency of TVS in all groups was 91.7% at 18 h of reperfusion. Delayed TVS at 3 h and beyond resulted in stepwise increases in circulating myoglobin during the early reperfusion period. TVS placement at 1 h of warm ischemia resulted in ischemia scores which were the same as the control group that only underwent iliac artery exposure with no occlusion or TVS placement. In contrast, delayed TVS at 3–6 h resulted in incrementally worse ischemia scores.

Maximum Duration of TVS Deployment

The maximum indwelling duration of a TVS has never been explicitly defined. Mathew et al. performed an 8-year retrospective review of their patients receiving an arterial shunt after a traumatic injury [34]. Forty two patients experienced penetrating trauma to the neck/torso (33.3%), upper-extremity (19.1%), and lower extremity (47.6%). Thirty-five patients survived their injuries and operative interventions. Nineteen had shunt dwell times of less than 6 h and did not experience a shunt-related complication. Sixteen had dwell times of greater than 6 h, of which five patients (31.3%) experienced a complication—loss of distal pulse, requiring a fasciotomy or extremity amputation. The authors' longest indwelling time has been 48 h allowing multi-injured patients more time for improved resuscitation before returning to the operating room for definitive arterial repair.

Recommendations Based on the Data

Based on the evidence reviewed, TVS shunts are effective extremity damage control adjuncts and can serve as an immediate conduit to diminish the deleterious effects of prolonged limb ischemia. The demonstrated patency rates and subsequent early

limb viability rates demonstrated by military studies argue against no attempt at early perfusion when temporary shunting is feasible. The location of TVS placement below the knee appears to be a larger determinant of TVS thrombosis than the type of TVS selected. In reviewing the military data, there were no bleeding concerns after TVS placement or mortalities related to TVS. The restoration of blood flow through TVS is deemed beneficial in the presence of concomitant bone and vascular injuries in both military and civilian extremity vascular cases. Civilian data supports TVS to reduce ischemia time, fasciotomies, and amputation rates as compared to non-shunted groups.

The evidence suggest that amputation rates are decreased when TVS are deployed in the absence of blast injuries or without the presence of a mangled extremity. The accelerated rate of limb perfusion through TVS correlates with decreased rates of compartment syndromes and the length of hospital stay. As TVS relates to morbidity and mortality in civilian penetrating trauma, TVS patients received fewer amputations and had improved mortality rates. The sequencing of operations for unstable or multi-injured patients is important when an extremity vascular injury is associated with torso hemorrhage. The review of the current literature suggests TVS as a viable alternative allowing surgeons and intensivists time to address other injuries and metabolic derangements prior to a definitive repair.

Review of Recommendations

- Temporary Vascular Shunts (TVS) in the race against ischemia, can be used safely in far-forward settings (evidence quality moderate; strong recommendation).
- TVS can be safely deployed with minimal bleeding concerns and without an associated increase in morbidity or mortality (evidence quality moderate; moderate recommendation).
- The restoration of blood flow through TVS is deemed beneficial in the presence of concomitant bone and vascular injuries, sequencing vascular repair ahead of unstable bone fixation (evidence quality moderate; strong recommendation).
- The accelerated rate of limb perfusion through TVS correlates with decreased rates of compartment syndromes and the length of hospital stay (evidence quality moderate; moderate recommendation).

A Personal View of the Data

Restoration of extremity blood flow should not be seen as a “countdown” from the traditional 4–6 h, but approached as “how fast” distal perfusion can be restored. The authors strongly admonish that a delay beyond 1 h leads to increased circulatory markers of ischemia that can be manifested clinically as significant reperfusion injuries leading to myocyte damage, increased rates of compartment syndrome and

amputations. TVS are a safe, reliable, and easy adjuncts to deploy to mitigate the deleterious effects of delayed revascularization.

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Difficult Decisions in Surgery: An Evidence-Based Approach Limb Salvage for the Mangled Extremity

36

Valentin Neuhaus and Hans-Christoph Pape

Introduction

A mangled extremity is an infrequent injury. The largest prospective study reported that on average 25 patients per year were admitted to level I trauma centers with this condition [1]. It comprises a heterogeneous group of injuries in both military and civilian settings. Mangled extremities have a tremendous negative impact on patients, causing psychological and bodily changes, pain, and disability as well as inability to work and social deprivation [2]. Further, they are a burden for families [3]. For health care providers, the decision is difficult, since amputation means no way back and salvage may lead to a long, painful journey with a poor outcome [2]. The injuries are difficult and complex to treat, and considerable experience is required for reconstruction and rehabilitation. They are usually the beginning of a long-term patient–doctor relationship with multiple hospitalizations and operations, which are prone to complications and have relevant effects on socioeconomic status.

The difficult decision with mangled extremities is whether to amputate or to salvage the limb. It is a demanding choice with emotional and functional implications. Sometimes, limb salvage can result in a painful limb with no sensation and no weight-bearing ability, which is inferior to an amputated limb with a prosthesis [4–6]. Ideally, an evidence-based approach to clearly defined aspects of the condition could determine which option (salvage vs. amputation) is superior. This chapter will provide some deeper insights into the definition of mangled extremity along with scores, decision-making, and predictors for a poor outcome.

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Search Strategy

First, we searched the Cochrane library and found no reviews of mangled extremities/limbs or open fractures in the past 5 years. Second, PubMed was searched for "mangled extremity*" OR "mangled limb*"; "limb-threatening" OR "leg-threatening"; "severe limb trauma" OR "severe leg trauma" OR "high-energy trauma"; amputation, salvage, or reconstruction. Only English and German literature was included, and a specific time frame was not imposed since some important studies were published long ago. Class I studies are lacking [7], and there are no randomized controlled trials. There are some prospective studies, but mainly observational publications and expert opinions. The PICO process was applied (Table 36.1).

Results

What Is a Mangled Extremity?

It is a combination of injuries to the bones, soft tissue, muscles, tendons, vessels and/or nerves after a high-energy mechanism or crush that can endanger the viability of the limb [8], according to Feliciano et al. of the American College of Surgeons, Committee on Trauma [9]. Gregory et al. stipulated that at least three of the four major tissue groups (bone, nerve, vessel, soft tissue) are injured in mangled extremity syndrome [10]. Kansal et al. defined it as a severe injury to a limb that leaves its viability in doubt [11]. De Mestral et al. defined a mangled extremity as either a crush injury or a combination of a severe fracture plus an arterial, soft tissue, or nerve injury (at least two of the last three distinctions), based on ICD Codes [12]. Scalea and his colleagues considered all high-grade open fractures with associated soft tissue injury to be mangled extremities [13]. The Lower Extremity Assessment Project (LEAP) group included high-energy injuries to the lower extremities with traumatic amputation below the distal aspect of the femur or injuries associated with some risk of amputation (e.g., Gustilo type IIIB and IIIc fractures, selected IIIa fractures, dysvascular limbs, major soft tissue injuries) with some exclusion criteria (e.g., associated central nervous system injury) [1].

Table 36.1 The PICO process

P (Patients) with	I (Intervention)	C (Comparator)	O (Outcomes)
Mangled extremity Mangled limb Severe limb trauma Severe leg trauma High-energy trauma Limb-threatening/leg-threatening injury	(limb) salvage Reconstruction Scores for decision-making	Primary amputation Secondary amputation	Salvage rate Return to work Quality of life Mortality Costs Outcome

The majority of mangled extremities are open fractures. Since tibial fractures are the most common open fractures, many studies of mangled extremities include open tibial fractures in general [14, 15] or just some distinct open tibial fractures (all grade III subtypes [16], only grade IIIC [17, 18], only IIIB [19, 20], or only IIIB and IIIC [3, 21]).

Scoring/Tools for Classification of Mangled Extremities

The Gustilo-Anderson classification is probably the most commonly used classification for open fractures. A simplified table of the Gustilo classification is [22]:

I. Transverse or short oblique fracture with a skin opening of <1 cm, usually from inside to outside.
II. Transverse or short oblique fracture with minimal comminution and with a skin laceration >1 cm.
III. Segmental or comminuted fracture with extensive soft tissue damage including skin/muscle/nerves/vascular structures.
    - IIIA Soft tissue coverage by primary suture, delayed closure and/or split-thickness skin-graft.
    - IIIB Plastic coverage of the soft tissue with a historical amputation rate of 16%.
    - IIIC Requires vascular repair to maintain viability with a historical amputation rate of 42%.

Despite its general use, the Gustilo-Anderson classification has some limitations. It is mainly based on the surface soft tissue defect (and not the functional tissue deficit), does not consider cofactors or comorbidities in patients, and has a low interobserver reliability [20, 23].

Several scoring systems have also been created, combining some of the relevant factors to help surgeons make decisions about mangled extremities (Table 36.2). The first scoring system specifically for mangled extremities was the Mangled Extremity Syndrome Index (MESI) published in 1985 [10]. Based on 17 patients, Gregory et al. defined criteria for a mangled extremity and included the Injury Severity Score (ISS), age, preexisting diseases, shock, and lag time to operation as predictive factors. The score is quite complex, some parts are not available during the first operation, and parts of it are based on subjective judgment.

The Predictive Salvage Index (PSI) was presented in 1987 [24]. Based on 21 cases, Howe et al. found the interval from injury to operative treatment, the level of the arterial injury, and the degree of musculo-skeletal injury predictive for limb salvage. The sensitivity was 78% and the specificity was 100%. Similar to the MESI, some information may be missing during the index procedure, and some information is subjective.

The simplest and most widely used score is the Mangled Extremity Severity Score (MESS), which was published between 1990 and 1994 [25–27]. It is based on

Table 36.2 The most often used scoring systems for classification of mangled extremities

Parameter	Ganga	HFS-97	LSI	MESI	MESS	NISSA	PSI
Skin	X	X	X	X			
Soft tissue					X	X	
Muscle	X	X	X				X
Tendon							
Nerve		X	X	X		X	
Artery		X	X	X	X	X	X
Vein			X	X			
Bone	X	X	X	X	X	X	X
Contamination	X	X				X	
Age	X			X	X	X	
Shock	X	X		X	X	X	
Time since injury/warm ischemia time	X	X	X	X	X 6 h	X 6 h	X
Comorbidities	X			X			
Concomitant injuries	X			X ISS			
Threshold	17	9	6	20	7	11	8

four readily available and simple criteria: skeletal/soft tissue injury, limb ischemia, shock, and patient age as a surrogate for patient comorbidities. A MESS score of more than 7 led to 100% amputation rates in 26 limbs with severe skeletal/soft tissue injuries with vascular compromise; it was also validated prospectively in 26 patients [26]. MESS was also validated in a combat setting. Duration of limb ischemia and shock were the most important factors since patients are usually young and the inciting mechanism tends be high-energy in a combat setting [28]. In contrast, some studies presented successful limb salvage in patients with a MESS up to 9, but they also recorded amputation in patients with a MESS lower than 7 [29]. The use of MESS remains controversial in children since the age criterion is always zero and only three criteria remain for calculation [30–32].

Russell et al. evaluated 70 limbs with major lower extremity arterial injury and constructed the Limb Salvage Index in 1991 (LSI) [6]. Six types of tissue injuries (skin, muscle, bone, nerve, arterial, deep vein) and duration of warm ischemia were included. They found a limb salvage index of 6 and greater as well as a type IIIC fracture with a nerve injury to be an absolute indication for amputation. However, the authors stated that scores cannot replace clinical judgment, and a detailed intraoperative examination is still needed.

In 1994, McNamara et al. introduced the nerve injury, ischemia, soft tissue injury, skeletal injury, shock, and age of patient score (NISSA) [33], which was evaluated in 24 patients with grade IIIB and IIIC open fractures of the tibia. In comparison with the MESS, the score includes nerve injuries and distinguishes soft tissue and skeletal injuries. Loss of plantar sensation is an important component of the NISSA score, which has been criticized.

The Hannover Fracture Scale-97 (HFS-97) was published in 1982 and modified in 2001 [34]. It is a scale consisting of 13 (cumbersome) parameters. The presence of vascular injury is an important component.

The Ganga Hospital Injury Severity Score was published in 2004 [19]. It is solely designed for IIIB open tibial fractures without vascular compromise. The score covers three components of the limb (covering tissues such as skin and fascia and their relation to the fracture site, skeletal tissues such as bones and joints, and functional tissues such as muscles, tendons, and nerves) and some general conditions and comorbidities of the patient [20]. The Ganga Hospital Injury Severity Score has been validated in other studies as well [23].

Many issues arise when using these scores. First, since all scores (except the MESS) were retrospectively investigated in a small subset of patients with different inclusion criteria and different outcome parameters, many authors questioned the importance, predictive utility, and predictive potential of these scores for long-term functional recovery [1, 35–41]. Most of the scores are specific in helping to predict limb salvage potential, but not sensitive. A low sensitivity is associated with delayed amputations, which can have a tremendous impact on a patient's life. There is no score that can clearly predict the ideal patient for amputation or for salvage. The dilemma about whether to proceed with either amputation or salvage remains unsolved [1, 42–45]. Second, most of the above-mentioned scores are built to assess fractures with an arterial injury. Hence, the sensitivity and specificity in mangled extremities without an arterial injury are low. Third, salvage of an extremity is not synonymous with salvage of a viable and functional limb. And last, the scores were developed in the 80s/90s, but there has been clear medical progress in the treatment of mangled extremities (fracture fixation, free tissue transfer, endovascular revascularization, microsurgical techniques, prosthetic implants, wound care technology) as well as success in limb salvage [46].

Many situations that lead to amputation are simply not 100% predictable (e.g., chronic pain, nonunion, failure of vascular repair, soft tissue and bone infections, and patients' preferences). The best predictors are hard to measure and/or subjective. A better scoring system is desirable [47]. However, the currently available scores are a good starting point to find the best treatment [13, 48]. Regardless, all patients must be assessed carefully, and case-by-case decision-making is still mandatory.

Decision-Making and Outcome Predictors

Treatment of mangled extremities consists first in hemorrhage control and second in the reduction of contamination and necrotic tissue via debridement. Debridement is the most important early step in treating mangled extremities ("debridement should be maximized to minimize the number of surgeries") [49]. Debridement reduces the inflammatory phase and reaction as well as the risk of infections and secondary amputations [50]. If we look at infection rates, time from injury to surgical

debridement is not as important as a thorough surgical debridement at a competent trauma center [51].

The ideal aim is a limb that can tolerate weight-bearing, have some protective sensation, and retain durable skin and soft tissue. The questions are whether this aim is possible at all and even advisable [13]. Sometimes, saving limbs can ruin lives, and amputation can be a better path [4, 5]. A large retrospective study reported a 21% amputation rate in 1354 patients [12]. The LEAP group reported 9% traumatic amputations, 11.3% immediate amputations, and 15.5% delayed amputations [52]. Amputations are associated with fewer complications, fewer operations, shorter length of stay, quicker time to recovery, and lower care-related costs at the beginning than reconstruction [42, 53–56]. However, quality-adjusted life years (QALYs) are lower in amputees, and only half return to work after 2 years [42]. Also, amputations are more expensive than reconstructions in terms of lifetime costs [57].

While primary amputation is a decision usually made by the surgeon, delayed amputations are initiated through shared decision-making, depending on the clinical course of treatment. Some surgeons even consider bringing the family to the operating room to get an impression of the massive destruction [8]. The decision to amputate early is challenging, as there is no way back. It seems clear that the level of the amputation should be as distal as safely achievable—the more distal an amputation, the better the function [58]. The extent of the local injury, the concomitant injury pattern and clinical presentation (shock), age and general health conditions, and the patient's preferences all influence the decision [12, 59].

Extent of the Local Injury

The magnitude of impact and subsequent extent of the local injury is one of the strongest predictors for primary or delayed amputation. A higher-energy mechanism causes greater soft tissue destruction and loss, more complex fractures (Gustilo-Anderson type III), more severe compartment syndrome, and worse vascular injuries. A crush above the knee is worse than below the knee. Blunt trauma is worse than penetrating injuries, but blast injuries have the worst outcome [1, 12, 29, 53, 60–63]. In a Swedish study, the need for soft tissue reconstruction (an indicator of trauma severity) was a significant predictor for amputation within 3 months after accidents [14].

Vascular Injuries

Vascular injuries are another important factor and must be assessed by physical examination, Doppler pulse device, ABI (less than 0.9 is pathological), or arteriogram/CTA. Some authors suggest performing a diagnostic arteriography in the operating room in case of an arterial injury [64]. Arterial injuries cause high

morbidity due to concomitant injuries and prolonged ischemia. Gustilo et al. reported an amputation rate of 42% for patients with an injury requiring vascular repair to maintain viability. Failure to revascularize leads to amputation. Again, a blunt mechanism is worse than penetrating damage [6, 65–67]. In the military setting, a higher amputation rate is reported due to explosive devices causing higher MESS/ISS [65]. Popliteal artery injuries have the worst prognosis since the popliteal artery has limited collateralization [66, 67].

The duration of ischemia/time to repair is important [68]. Arterial injuries, especially with revascularization delays of greater than 6 h, were associated with a bad outcome [12, 69, 70]. Lange et al. recommended amputation in crush injuries with more than *6 h of warm ischemia* [69]. The 6-h threshold is widely accepted; however, there are also some reports questioning this time threshold [71]. Bone stabilization before vascular repair was not associated with amputation [66], but sometimes, in severe limb ischemia, vascular repair should be done first. The goal must be to establish arterial blood flow as soon as possible. Some authors suggest shunting as early as possible and performing a prophylactic fasciotomy to reduce the risk of compartment syndrome and delayed amputation [72]. Most shunting experience comes from war surgery, showing that shunting in damage control situations did not worsen the outcome and may serve as a bridge before definitive repair [73, 74]. In a large case series from Iraq and Afghanistan, shunting and reconstruction had outcomes similar to initial reconstruction, with a limb salvage rate of 80%; the exception was for early shunt thrombosis which did not increase the amputation rate [75, 76].

Nerve Injuries

The extent of functional tissue (muscles, tendons, and nerves) loss is of paramount importance. In 1985, Lange et al. recommended to proceed with amputation in case of a complete *posterior tibial nerve disruption* [69], since complete sciatic or posterior tibial nerve transection was associated with a very poor functional outcome. However, an insensate foot is no longer an indication to proceed with amputation, since some patients with an insensate foot at presentation had successful limb reconstruction and a sensate foot in the long-term. A nerve dysfunction (due to reversible ischemia or neuropraxia) cannot be clinically distinguished from a nerve disruption [77].

Concomitant Injury Pattern and Shock

The concomitant injury pattern is another important factor in decision-making. Patients with a higher ISS have a higher trauma load and cannot withstand the persistent toxic load of a traumatized leg [7]. An amputation may be life-saving.

Patients with a MESS between 7 and 9 and an ISS of more than 17 should undergo amputation; primary amputation is recommended in patients with a MESS of 10 or higher, irrespective of the ISS [78]. A severe head injury (AIS > 2) was also a risk factor for early amputation [12]. Early amputation is a life-saving procedure—life before limb—in patients with shock at admission [12].

Age and General Health Conditions

Age was a predictor for a poor outcome in a study from the USA and a study from Taiwan [79, 80]. Yet there are also contradictory results concerning age, as age was not a predictor for early amputation in patients with popliteal injuries [64]. Nicotine or alcohol abuse, insurance status, and social aspects also play major roles in outcomes. Non-smokers, those with higher education and socioeconomic status, and younger people were associated with better outcomes and were more likely to return to work [81, 82].

Patients' Preferences

Patients prefer limb reconstruction from a psychological point of view. However, social integration and quality of life were similar for reconstruction and amputation [83–85]. Aravind interviewed 20 patients after either amputation or reconstruction and found similar levels of satisfaction [3]. Satisfaction after 2 years depends more on function, return to work, pain, and depression than on any injury or treatment characteristics [86].

Reconstruction and Delayed Amputation

Soft tissue defects in combination with fractures need coverage to minimize the risk of wound infection, osteomyelitis, nonunions, and secondary amputation [87, 88]. Skin grafts, local flaps, cross leg flaps, and free flaps (ideally with microvascular reconstruction beyond the zone of injury) are options [88].

Delayed (secondary) amputation remains a problem, causing significant physical, psychological, familial, and financial suffering. Patients need re-hospitalization and reconstructive surgeries, which are prone to complications. After initial limb salvage, patients need long-term follow-up because some patients progress to limb loss due to chronic pain, nonunion, inadequate vascular repair, and soft tissue or bone infections, including sepsis [89, 90]. The definition of late amputation varies in the literature, with some advocating a time threshold (e.g., 12 weeks after the injury) [91] and others defining late amputation as an amputation after the initial hospitalization (LEAP group). MESS was prognostic for late amputation, especially in patients with an arterial injury [62, 63, 71, 92].

Outcome

The clinical outcomes and self-reported disability for amputation and reconstruction are similar in the long-term follow-up, but both present with quite a high disability level [1, 21, 42, 82–85, 93]. Current literature does not show any superior outcome of one treatment over the other. The localization of the amputation and social factors (e.g., rank in the military or membership in the Special Forces) influenced the ability to deploy [94].

Mangled Upper Limb Injuries

Mangled upper limb injuries are less common than lower limb injuries. The scores must be used with caution and interpreted carefully since upper limb anatomy (especially vascularity), function, and treatment goals are different [95]. Upper limb injuries are less likely to be amputated [35] since the critical time of ischemia is usually longer (up to 10 h), the prostheses are not as functional, and the loss of the upper extremity may also be much more emotional [8]. In addition, shortenings are much better tolerated in the upper body than shortenings of the lower leg.

Recommendations Based on the Data

While there is abundant literature on this subject, most of it has a low quality of evidence (Table 36.3). The LEAP study group published many prospective studies, and skewing of the results due to possible duplication is evident [83].

Assuming that the mangled extremity will be salvaged whenever possible [108], some mangled extremities are still non-salvageable or irreparable. The decision to amputate is guided by systemic and local injury characteristics [12]. A higher ISS, concomitant severe head injuries, a higher-energy trauma mechanism, and a higher extent of local injuries are associated with amputation.

The duration of ischemia/time to repair is important. Arterial injuries with revascularization delays of greater than 6 h were associated with bad outcomes. The presence of an insensate foot at initial presentation is no longer an indication to proceed with an amputation. Non-smokers, those with higher educational or socioeconomic status, and those of a younger age were associated with better outcomes and return to work.

All injuries should be surgically explored before a decision to amputate is made [35]. Prompt amputation helps to avoid delayed infection in non-salvageable limbs [14, 100]. Patients face fewer psychological consequences with earlier amputation. If amputation is needed, amputation is recommended at the most viable distal level, where you can safely close the wounds later. Patients after reconstruction and after amputation have similarly poor long-term outcomes [82]. Still, reconstruction is desirable due to less social disintegration and lower total costs [56].

Table 36.3 Overview of the literature

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
De Mestral [12]	Canada/2013	1354	Retrospective, multicenter (222), National Trauma Databank (NTDB)	In total 21% amputation during the first hospitalization; 9% had early amputation—Predictors for early amputation were: Severe head injury, shock, higher-energy mechanism (MVC) and limb injury type (crush at/above knee) associated with early amputation (but not by age or comorbidity level)	The decision to amputate early may be guided by systemic and local injury characteristics.	Moderate
MacKenzie [82]	USA/2005	353	Interview by the phone 48 months after the injury	Only one in three patients has a sickness impact profile which is similar to the general population of similar age and gender.	Patients after reconstruction and after amputation have similar poor long-term outcome.	Moderate
Bosse [42]	USA/2002	569	Prospective, multicenter (8), LEAP	The sickness impact profile was similar between amputees and patients with limb salvage 2 years after the accident	Reconstruction and amputation have similar 2-year outcome.	Moderate

Dagum [96]	Canada/1999	55 severe lower extremity injuries, type IIIB and IIIC	Retrospective Prospectively assessing the overall health status and specific dysfunction	9 patients needed primary amputation. 5 patients underwent secondary amputation. Amputation index scores predicted an amputation in 32% and did not correlate with the physical outcome score.	The disability is primarily physical and not psychological. None of the patients would have preferred a primary amputation.	Low
Hoogendorn [97]	The Netherlands/2001	64 patients with grade III open tibial fractures	Retrospective	43 patients with limb salvage and 21 patients with amputation	The injury has a tremendous impact on patient's life, irrespective of the treatment, but the quality of life was similar	Low
Gopal [98]	UK/2004	34 grade IIIB and IIIC open tibial fractures in 33 patients	Retrospective, after a mean follow-up of 46 months	34% needed further surgery to achieve bony union, mean time to union was 41 weeks. 2 patients (6%) developed a deep infection. 7 patients (21%) complained about knee stiffness, 19 (56%) about ankle stiffness. 12 patients (41%) returned to work.	All patients were pleased to have retained their limb.	Low
Bosse [1]	USA/2001	601 patients with 633 limbs	Prospective, multicenter (8), LEAP	Evaluation of the clinical utility of five scores 9% traumatic amputations 11.3% immediate amputations 15.5% delayed amputations	The scores have a high specificity but a low sensitivity and must be used with cautious.	Moderate

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Aravind [3]	USA/2010	20 with either flap coverage or amputation as treatment for type IIIB or C open tibial fractures	Interview	Most of the patients were satisfied with the outcome.	It is difficult for patients to prefer one medical treatment over another, the surgeon was the main force behind a decision.	Low
Rajasekaran [19]	India/2006	42 type IIIA open tibial fractures and 67 type IIIB tibial fractures	Validation of a score	The ganga hospital score had a higher sensitivity, specificity and positive/negative predictive value than the mangled Extremity severity score	The ganga hospital score is simple and reliable	Low
Ly [36]	USA/2008	407 limbs after successful limb salvage	Prospective, multicenter (8), LEAP	None of the scoring systems were predictive of the physical or the psychosocial recovery	Current scoring tools are not predictive of the functional recovery	Moderate
Kauvar [75]	USA/2019	257 patients with a wartime femoropopliteal arterial injury (Iraq/Afghanistan)	A prospective database was queried	Limb salvage rate was 80%, 62% of amputations were performed within 2 days, shunts were used for 5 h on average	Staged femoropopliteal injury care is associated with similar limb salvage to initial reconstruction at a larger field hospital	Moderate
Van Dongen [99]	The Netherlands/2017	84 service members repatriated from Afghanistan with severe lower extremity injuries (AIS>2)	Online survey	Well-being, social and cognitive functioning were lower in battle than in non-battle injured patients. Amputees experienced higher Well-being and less pain compared to patients after limb salvage.	Amputation is not a failure for casualty and surgeon.	Low

Hertel [56]	Switzerland/1996	39 patients with severely injured legs	Retrospective	Number of interventions, rehabilitation time and costs in the first four years were higher in the reconstruction group	Still, reconstruction is advisable due to better functional outcome, less social disintegration, and lower total costs (including pensions).	Low
Rush [28]	USA/2007	49 patients with 60 extremities in a combat setting	Retrospective	The MESS was 8 for the 8 amputations, and 2.5 in 50 salvaged extremities	The MESS correlated with amputation. In the combat setting (young patients with high-energy trauma) shock and time since injury (warm ischemia time) are the most important factors distinguishing between amputation or salvage.	Low
Elsharawy [35]	Egypt/2005	62 patients with an arterial injury in mangled extremities	Prospective	MESS and MESI were not associated with limb salvage	All injuries should be surgically explored before a decision to amputate is made.	Moderate
MacKenzie [52]	USA/2000	601 patients	Prospective, multicenter (8), LEAP	Demographic description of the patients; no significant differences were found between amputees and patients after limb salvage	Patient characteristics did not influence the decision process.	Moderate
Doucet [29]	USA/2011	850 (civilian) vs. 115(military) open tibial fractures	Comparison of two registries	45 amputations in 850 open tibial fractures in the civilian setting vs. 21 amputations in 115 open tibia fractures in the military group	Blast injuries are worse and MESS is not predictive	Moderate

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Harris [55]	USA/2009	545 patients	Prospective, multicenter (8), LEAP	Amputation group: 5.4% revision amputation, 34.2% wound infection Salvage group: 3.9% late amputation, 23.3% wound infection, osteomyelitis (8.6%), nonunion (31%)	Patients must expect a significant number of complications, additional procedures, and hospitalizations.	Moderate
Jain [100]	UK/2012	40 patients with 42 amputations	Prospective database, retrospective analysis	Amputation within 5 days was associated with significantly fewer stump infections.	Prompt amputation helps to avoid delayed infection in non-salvageable limbs	Moderate
O'Toole [86]	USA/2008	463 patients	Prospective, multicenter (8), LEAP	Patient demographic, injury characteristics, and treatment did not correlate with satisfaction.	Patient satisfaction after 2 years rather depends on depression, walking speed, pain, and return to work.	Moderate
MacKenzie [81]	USA/2006	423 patients	Prospective, multicenter (8), LEAP	Differences in functional outcome after amputation and reconstruction are similar, but poor. Younger age, white, non-smoker, and higher education were associated with higher return to work	Function and pain are predictors for return to work.	Moderate

Sharma [37]	India/2003	50 patients with 56 mangled extremities	Single surgeon experience, prospective	The MESS was 8.6 in the group with amputation and 4.7 in the group with reconstruction	Many patients refused primary amputation. MESS was highly predictive for amputation. Nerve injuries and irreparable soft-tissue loss should be given an extra point.	Moderate
Chang [80]	Taiwan/2019	45 patients	Retrospective, letter to the editor	24.4% (n = 11) underwent primary amputation within 2 weeks, 3% (n = 1) delayed amputation within 5 months.	MESS was a highly specific predictor for amputation with a moderate sensitivity. Age was the single predictor for outcome.	Low
Dahl [101]	Denmark/1995	53 patients	Matched pair comparison	Patients after free tissue transfer had significantly more often pain and swelling compared to patients after amputation. No significant differences regarding social results.	The authors concluded that the long-term functional and social results were similar for patients after amputation and after free tissue transfer.	Moderate
Soni [17]	UK/2012	18 patients with IIIC open tibial fractures	Retrospective	15 patients with reconstruction and 3 patients with amputation; 39% did not return to work.	Patients complained about pain and consecutively limited activities; the MESS was a significant predictor of the functional outcome, however with a cut-off of 10.	Low

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Tinali [18]	Turkey/2017	22 patients with IIIC open tibia fractures	Retrospective and questionnaire	Only 7 patients reported no pain in the long-term follow-up. No patient wanted a primary amputation (in the retrospect).	Scoring systems and the ischemic time are not the only predictors of amputation.	Low
Brown [16]	USA/2010	84 patients with 85 extremities	Retrospective cohort study of British military casualties in Iraq and Afghanistan	20 infected and 65 uninfected mangled extremities.	Tourniquet use in the field and fasciotomy were associated with infections—Likely reflective of injury severity	Low
Huh [91]	USA/2011	213 combat-related type III open diaphyseal tibia fractures	Retrospective	78% of the patients were treated definitively with limb salvage,17% with early amputation, and 5% with late amputation.	Soft-tissue injury requiring flap coverage and infections were associated with late amputation.	Low
Krueger [94]	USA/2014	953 U.S. service members who sustained major extremity amputations	Retrospective	5% of the amputees deployed	A transtibial amputation, senior rank and being a member of the special forces was associated with deployment.	Moderate

Barla [85]	France/2017	36 patients with 38 extremities	Retrospective	20 patients with amputation and 16 patients with limb salvage. The MESS was significantly higher in the amputation group. 61% infection rate in the limb salvage group, which was significantly higher than in the amputation group. The quality of life was similar.	Amputation is not a failure, rather a necessary choice.	Low
O'Sullivan [102]	Ireland/1997	54 limbs in 51 patients with type IIIB or C tibial fractures	Retrospective	Comparing MESS and LSI	Both indices were helpful and predictive, however neither score was absolutely accurate and reliable in daily practice.	Low
Helfet [26]	USA/1990	Reviewing 25 trauma victims with 26 severe lower extremity open fractures with vascular compromise and prospectively evaluated in 26 lower extremity open fractures with vascular injury	Retro- and prospective	Developing the MESS	The MESS is a simple, readily available, and highly accurate scoring system of objective criteria	Moderate
Russell [6]	USA/1991	70 limbs with major lower extremity arterial injuries	Retrospective	Evaluating the LSI 73% salvage vs. 27% amputation (2/3 early and 1/3 late)	The LSI is a guide for accurately evaluating trauma to the lower extremity	Low

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Tampe [14]	Sweden/2014	3777 patients with open tibial fractures; 342 patients with open tibial fractures and soft-tissue reconstruction	Analysis of the Swedish National Patient Register	3.6% amputations in all open tibial fractures	Age older than 70 years (OR 2.7) and reconstructive surgery (OR 3.1) were associated with a higher risk for amputation. Reconstruction later than 3 days was also associated with a poorer outcome.	Moderate
Parrett [15]	USA/2006	290 open tibia fractures	Retrospective	Comparing 3 "4-year periods" (1992–2003), no changes in infection/amputation/nonunion rates with a minimal follow-up of 1 year	There is a trend over time with fewer free flaps and more delayed closures and skin grafts	Low
Slauterbeck [25]	USA/1994	37 patients with 43 mangled extremity injuries	Retrospective	9 extremity injuries with a MESS of 7 and more were amputated, 34 with a MESS of 6 or less were salvaged	The MESS is an early and accurate predictor	Low
Fagelman [32]	USA/2002	36 children with grade IIIB and IIIC open lower extremity fractures	Retrospective, two pediatric trauma centers	The MESS prediction was accurate in 93%.	The MESS should be considered in children with mangled extremity.	Low
Johansen [27]	USA/1990	Patients with severe lower extremity injuries	Retrospective analysis (26 limbs), and prospective trial (26 limbs)	MESS predicted amputation with 100% accuracy	MESS may be useful	Moderate

Lange [69]	USA/1985	23 open tibial fractures with limb-threatening injuries	Retrospective	61% amputation rate	Crush injuries, segmental tibial fractures and delay in vascular repair of more than 6 h were associated with amputation.	Low
Georgiadis [54]	USA/1993	45 patients with an open tibial fracture and severe soft-tissue loss	Retrospective, comparing limb salvage vs. amputation	Patients with limb salvage had longer till full-weight-bearing, were less able to work, and had higher hospital costs. The quality of life was similar	Complications and difficulties in the salvage group are common. Amputation resulted in quicker time to recovery.	Low
Durham [41]	USA/1996	23 upper and 51 lower extremity injuries	Retrospective, comparing MESS, MESI, PSI, LSI	Sensitivity was between 79 and 100%, specificity was between 50 and 83%, positive predictive value 88–95%, negative predictive value 50–100%.	Prediction in individuals is problematic, and functional outcome was not predictable.	Low
Casey [89]	USA/2015	94 patients presenting to a limb preservation clinic	Retrospective	Common reasons for delayed amputation included chronic pain, osteomyelitis and soft-tissue infections.	Many patients need a secondary amputation after initial successful limb salvage. Long-term follow-up is required.	Low
Simmons [71]	USA/2011	51 patients with a popliteal artery injury	Retrospective	18% amputations, patients with the need for amputation had a higher MESS, however time from injury to repair had no influence.	MESS was the best predictor for amputation in this cohort. 6 h and more till repair was not a risk factor for amputation.	Low
Fochtmann [62]	Austria/2014	93 patients with third-degree open lower limb fractures	Retrospective	12% secondary amputation. MESS was significantly higher in the amputation group.	MESS was highly predictive.	Low

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Madhuchandra [23]	India/2014	40 type IIIA and IIIB open tibial fractures	Prospective, validation of the ganga hospital score	Sensitivity was 100%, specificity was 95%	Ganga scoring system is reliable and prognostic.	Moderate
Robertson [103]	New Zealand/1991	152 patients with severely injured lower limbs	Retrospective	All patients with a MESS >6 required amputation. Some patients with a score of <7 had secondary amputation.	MESS is predictive.	Low
Ray [79]	USA/2019	108 patients undergoing infra-inguinal arterial bypass for trauma	Retrospective	MESS was strongly predictive for a poor outcome.	Primary amputation can be considered in patients with MESS >10.	Low
Song [63]	China/2017	41 patients with a grade IIIC lower limb injury	Retrospective	Primary amputation was performed in 15%. Secondary amputation was necessary in 34% of the remainders.	MESS (7+), complex fractures, ischemia >6 h, and compartment syndrome were associated with amputation.	Low
Kim [70]	South Korea/2019	24 patients with lower extremity trauma and need for femoropopliteal repair	Retrospective	21% amputation rate	ISS >20, MESS >7, and internal fixation were associated with amputation	Low
Howe [24]	USA/1987	12 tibial-fibular and 5 femoral fractures with an associated major vascular trauma and four other cases with a combined orthopedic as well as vascular trauma	Retrospective	43% amputation rate	Predictive salvage index was constructed.	Low

Kumar [104]	India/2007	58 patients with 61 limbs	Retro- ($n = 25$) and prospective ($n = 36$)	The MESS was 4.5 in the salvaged group and 8.8 in the amputation group.	MESS was predictive	Moderate
McNamara [33]	USA/1994	24 patients with IIIB and IIIC tibial fractures	Retrospective	Including nerve injury as well as soft tissue as well as skeletal injury in the score	NISSA was constructed, higher sensitivity (82%) and specificity (92%) than the MESS	Low
Caudle [90]	USA/1987	62 type III open tibial shaft fractures	Retrospective	11 IIIA fractures in 10 patients: 27% nonunions 42 IIIB fractures in 42 patients: 43% nonunions, 17% secondary amputations 9 IIIC fractures in 9 patients: 78% secondary amputations	Type IIIC fractures have a poor outcome, all patients have major complications—Primary amputation should be considered in these cases.	Low
Sisli [68]	Turkey/2016	90 cases with combat-related vascular injuries (upper and lower extremities)	Retrospective	21 limbs were amputated (23%), and 69 were salvaged.	The extent of the tissue disruption (bony fractures, nerve injuries) and the duration of ischemia were the major predictors for amputation. MESS should not be used as the sole foundation for or against amputation.	Low
Yeh [78]	Taiwan/2016	242 patients with type IIIB or IIIC lower extremity fractures	Retrospective	14% primary amputation 20% delayed amputation Patients with an ISS > 18 had a higher secondary amputation rate	The total trauma load (measured with the ISS) adds information if a patient with a MESS of 7–9 should be salvaged or amputated.	Low

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
Fairhurst [93]	New Zealand/1994	12 patients with a below-knee amputation and 12 patients with a salvaged limb	Retrospective, interview and examination one year after completion of the treatment	Early amputees had fewer operations, shorter length of stay, returned to sport and work earlier. However, neither group returned to normal levels.	Amputation should be considered with a borderline salvageable injury.	Low
Lin [92]	Taiwan/1997	36 grade IIIC open lower extremity fractures in 34 patients—Primary amputees were excluded	Retrospective, 2-year follow-up	25% secondary amputation rate MESS was predictable for secondary amputation as well as long-term function	More severely injured limbs have a poor functional outcome. Every patient needed reconstructive surgery. MESS is helpful in decision-making, however the threshold can be raised to 9.	Low
Loja [47]	USA/2017	230 patients with a lower extremity arterial injury	Retrospective, using data from a prospective registry (PROOVIT)	A MESS of 8 predicted amputation only in less than half of the cases.	It is time for a revision of the MESS	Moderate
Hohenberger [45]	Austria/2019	71 patients with arterial reconstruction	Retrospective	27% of patients had a MESS of >6, the amputation rate was not statistically higher (21%) than those with a MESS of <7.	MESS is an inappropriate predictor	Low

Gregory [10]	USA/1985	17 patients with mangled extremities	Retrospective	Injuries were retrospectively classified, and additional multisystem scoring items were added.	The MESI was built to distinguish between functionally retrievable versus probably irretrievable extremities.	Low
Roessler [105]	USA/1991	80 patients	Retrospective	Nerve, bone, and soft-tissue injuries dictated the need for primary amputation. The absence of a pulse or Doppler pulse was critical for delayed amputation. Fluid balances of greater than 3 liters within 24 h indicated systemic compromise and warranted a more aggressive treatment (amputation).	The amputation rate is high in patients without distal pulse on presentation.	Low
Poole [60]	USA/1994	46 patients with 48 mangled lower extremities	Retrospective	50% amputation rate—Increased severity of soft-tissue injury was associated with amputation, especially injury to the sciatic or tibial nerve.	Decisions regarding amputation require careful judgment and cannot always be made during the first procedure.	Low
Bondurant [106]	USA/1988	263 patients with grade III open tibia fractures	Retrospective	16% amputation rate Patients with primary amputation: LOS 22 days, 1.6 surgical procedures, 29′000 USD costs Patients with delayed amputation: LOS 53 days, 6.9 surgical procedures, 53′000 USD costs	Delayed amputation is associated with a medical and economic impact.	Low

(continued)

Table 36.3 (continued)

First author	Country/year	Patients (*n*)	Methods	Results	Conclusion	Quality of evidence
DuBose [107]	USA/2015	542 vascular injuries from head to lower leg (26% lower extremity)	Prospective, 14 centers	CT-angiography and exploration were the most used diagnostic modalities. 51% were treated nonoperative. Amputation rate was 7.7%, mortality rate was 12.7%	This registry provides needed information about the optimal diagnosis and treatment of vascular injuries.	Moderate
Bosse [77]	USA/2005	55 patients with an insensate extremity at presentation	Prospective, multicenter (8), LEAP	29 patients were salvaged, 55% of them had normal plantar sensation at 2 years after the injury.	Initial plantar sensation is not prognostic of long-term plantar sensory status.	Moderate
Pollak [51]	USA/2010	315 patients with severe high-energy lower extremity injuries	Prospective, multicenter (8), LEAP	27% had an infection within 3 months after injury.	Time from injury to operative debridement was not a significant predictor for infection.	Moderate
Wlodarczyk [72]	USA/2018	291 patients with combined vascular and orthopedic trauma	Retrospective, multicenter (6)	25% had a temporary shunt first, 33% had definitive arterial repair, and the reminders had orthopedic fixation first.	Morbidity (compartment syndrome, rhabdomyolysis) is reduced with a temporary shunt first.	Low
Bonanni [44]	USA/1993	89 patients with severe lower extremity injuries	Retrospective	Evaluating the MESI, MESS, PSI, and the LSI	No index/score was reliable.	Low
Swiontkowski [53]	USA/2002	527 patients	Prospective, multicenter (8), LEAP	23% amputation rate, 46% of them were immediate and 54% were delayed	The extent of the soft-tissue injury was the most important factor to proceed either with amputation or limb salvage.	Moderate

Summary of Recommendations

- The currently available scores have a high specificity but a low sensitivity and must be used with caution (moderate evidence quality, strong recommendation).
- The decision to amputate is guided by systemic and local injury characteristics (moderate evidence quality, strong recommendation).
- Arterial injuries with revascularization delays of greater than 6 h were associated with a bad outcome (moderate evidence quality, strong recommendation).
- An insensate foot at initial presentation is no longer an indication to proceed with amputation (moderate evidence quality, weak recommendation).
- Prompt amputation helps to avoid delayed infection in non-salvageable limbs (moderate evidence quality, strong recommendation).
- Patients after reconstruction and after amputation have similarly poor long-term outcomes (moderate evidence quality, strong recommendation).

A Personal View of the Data

It is a difficult and emotional decision whether to proceed with amputation or salvage, both for the patient and for the surgeon. Tell the patient that you will carefully examine the limb in the OR, that you will save the limb if it is possible to give them a foot they can use, but that an amputation could well be required. Patients must be informed that a normal functioning limb is rarely achieved, and the long-term outcome is similar for amputation and limb salvage.

Amputation is not a failure of limb salvage; it is the best treatment in selected cases. “Do what you feel is right, on the first night!” Do not delay an inevitable amputation. It can make the emotional process harder for both the patient and the surgeon.

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Part X

Pediatric Trauma

The Use of FAST in the Pediatric Trauma Setting

37

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Introduction

Trauma remains the greatest cause of mortality in children older than 1 year of age in the USA, and the majority of these injuries are due to blunt trauma [1, 2]. The role of the Focused Assessment with Sonography for Trauma (FAST) exam in pediatric trauma remains controversial for several reasons. Proponents argue that pediatric patients would benefit just as adult patients who have suffered blunt trauma. Namely, FAST can help diagnose intra-abdominal injuries (IAI) accurately, quickly, cost-effectively, and without radiation [3–5]. The high specificity of FAST in adult patients has led to the inclusion of FAST as an option replacing diagnostic peritoneal lavage (ATLS manual [5, 6]) with a consequent decrease in CT scans. Whether these benefits truly extend to a pediatric population is unclear.

Concerns exist about the application of FAST to a pediatric population. Several meta-analyses have clearly demonstrated the decreased sensitivity and specificity of FAST exams in children [6, 7]. As a consequence, whether FAST exams meaningfully affects clinical practice algorithms is unclear. Additionally, there are concerns regarding a high level of technician-dependent variability, as well as the lack of training for emergency medicine physicians and surgeons in performing FAST exams in pediatric patients.

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Trauma centers that do not routinely utilize FAST exams in their triage algorithm instead rely on history, mechanism of injury, physical exam, and varying labs to determine whether further imaging or intervention is needed. CT scan is usually the definitive imaging choice. The purpose of this review was to evaluate the effect of FAST exams on clinical outcomes in the pediatric trauma population in comparison with triage without FAST.

Search Strategy

A literature search was performed in Medline, EMBASE, and ISI Web of Science using the terms "pediatric trauma FAST" and "pediatric trauma ultrasound." Systematic reviews, prospective randomized trials, prospective observational studies, and retrospective reviews published in the past 10 years (2010–2019) were included. Case reports and series and articles that were not in English were excluded. Studies describing only the test characteristics of FAST compared to other imaging or laboratory studies without evaluating relevant clinical outcomes were also excluded. All studies excluded patients with penetrating trauma. Thus, the PICO evaluation is limited to pediatric patients with blunt trauma (Table 37.1). In total, one Cochrane review, one meta-analysis, one randomized controlled trial, and three prospective observational studies were analyzed.

Results

Missed Injuries

Numerous studies of varying quality have evaluated the rate of injuries ~~that are~~ missed by FAST exam as compared to either CT scan, operative evaluation, or clinical follow- up. This is of particular concern in children because clinically significant intra-abdominal injuries, such as isolated intraparenchymal injuries, can occur without any free intraperitoneal fluid [5, 8, 9]. Two recent meta-analysies assessed the pooled data of selected studies and showed similarly poor sensitivity of FAST exams (Table 37.2).

Table 37.1 PICO evaluation

P (Patients)	I (Intervention)	C (Comparator)	O (Outcomes)
Pediatric blunt trauma patients	Standard trauma workup + FAST	Standard trauma workup alone	1. Mortality. 2. Missed injuries. 3. CT use. 4. Cost. 5. Need for operation, including non-therapeutic laparotomy. 6. ED LOS. 7. Overall LOS.

The 2019 meta-analysis by Liang et al. included eight prospective studies which included only hemodynamically stable pediatric patients who presented to the ED after blunt trauma and underwent a FAST exam performed by an emergency medicine or surgical staff member [7]. CT scans, laparotomy, hospital observation, and/or outpatient follow-up served as the reference standard for assessing FAST performance. Among the combined population of 2135 patients, the pooled sensitivity of the FAST exam was only 35% (95% CI 29–40%) and the pooled specificity was 96% (95–97%). The positive likelihood ratio was 10.84 (95% CI 4.36–26.92) and the negative likelihood ratio was 0.64 (95% CI 0.51–0.80). The authors conclude that, in this specific subset of pediatric trauma patients, a positive FAST indicates that an intra-abdominal injury is likely, however, a negative exam should not preclude further diagnostic evaluation.

In 2018, Stengel et al. published a Cochrane review on point-of-care ultrasonography (POCS) for diagnosing thoracoabdominal injuries in patients with blunt trauma [6]. POCS results were compared to CT, MRI, thoracotomy/thoracoscopy, laparotomy/laparoscopy, autopsy, or any combination of these. A subset analysis of the ten prospective and retrospective studies enrolled both adult and pediatric patients of which only 1384 were children. Estimated test characteristics were sensitivity 0.62 (95% CI 0.47–0.75), specificity 0.91 (95% CI 0.81–0.96), positive likelihood ratio 6.9 (95% CI 2.5–18.8), and negative likelihood ratio 0.42 (95% CI 0.26–0.95). The authors then performed an analysis of 1000 virtual patients based on an observed median prevalence of thoracoabdominal injury of 31% in these ten studies (i.e., pretest probability of injury). POCS would miss injuries in 118 children and falsely suggest an injury in another 62 children. Thus, the authors conclude that, especially in children, the low sensitivity of POCS means that a negative exam must be verified by a reference test.

CT Use

Several studies evaluated whether the addition of FAST exams decreased CT scan rates. Each study implemented a different protocol for when to perform a FAST exam, but the decision to obtain a subsequent CT scan was always at the provider's discretion and not directed by any protocol (Table 37.2).

In the randomized control trial by Holmes, patients were randomized to receive a standard trauma workup with or without FAST [10]. Adding FAST decreased CT utilization rates by only 2.2% (95% CI -8.7% to 4.2%, $p = 0.50$), which did not meet the authors' preselected threshold for clinical significance of a 10% reduction. Similarly, the prospective observational study by Calder showed no significant difference in CT scan rates after FAST when compared to no FAST (41.0 vs 46.1%) [11]. Unlike Holmes' study, the decision to obtain a FAST was left to individual trauma teams at the 14 level 1 pediatric trauma centers in Calder's study.

The prospective observational study by Menaker suggests that FAST exam may decrease CT rates in a subset of trauma patients [12]. In this study, trauma providers' suspicion for intra-abdominal injury was classified into five categories (very

Table 37.2 Summary of study results

Study	Number of eligible patients	Outcome classification	Conclusion	Quality of evidence
Stengel (Cochrane review)	1384	POCS sensitivity 0.62 POCS specificity 0.91	Due to the low sensitivity of POCS test, a negative exam must be verified by reference test	High
Liang (meta)	2135	FAST sensitivity 35% FAST specificity 96%	Negative FAST should not preclude further evaluation Positive FAST means IAI is likely	High
Holmes (RCT)	975 children and adolescents <18 year old	FAST was associated with —Increased rate of missed injuries by 0.2% ($p = 0.50$) —Decreased CT scan rate by 2.2% ($p = 0.50$) —Decreased hospital charges by $1180 ($p = 0.67$) —Increased laparotomy rate by 1.1 —Decreased ED LOS by 0.04 h ($p = 0.88$) —Decreased hospital LOS by 10.7 h	FAST does not improve clinical care or resource utilization.	High
Calder (prospective observational)	2185 children and adolescents <16 years old	No significant difference in CT scan rate with or without FAST (41.0% vs 46.0%) No difference in rates of transfusion, surgery/ angiography based on FAST exams >50% of those requiring transfusions, surgeries, angioembolizations had a negative FAST exam	In pediatric blunt trauma patients, FAST does not significantly impact CT use or injury management.	Low
Menaker (prospective observational)	6468 children and adolescents <18 years old	13% decrease in CT scan use with FAST in low or moderate risk patients	Decreased CT scan use with FAST exams only in patients with low or moderate risk for IAI	Low

Table 37.2 (continued)

Study	Number of eligible patients	Outcome classification	Conclusion	Quality of evidence
Scaife (prospective observational)	183 children and adolescents <18 years old	Surgeon would have cancelled CT scan after FAST and physical exam in 48% of cases 80% of patients requiring transfusions had negative FAST	Suggests FAST may decrease CT scan rates in some patients	Low

low, low, moderate, high, very high) based on initial evaluation and labs. Providers then decided whether or not to perform a FAST exam and/or subsequent CT scan. Under this algorithm, FAST exam was associated with decreased CT scan rates only in patients considered to be at low and moderate risk for IAI by the treating physician (13% decrease in CT scan rate in both groups). The data from the prospective observational trial by Scaife et al. also suggest that FAST may decrease CT scan rates in some patients. This study only included trauma patients who underwent FAST exams so no comparison can be made between FAST and no FAST groups. Nonetheless, when providers were queried whether they would obtain a CT scan before and after a FAST exam, they stated that they would have cancelled a CT in 48% of cases after the FAST exam. The CT was actually cancelled in only 15% of cases, however, and the reasons for this discrepancy are not stated.

Based on these data, determining exactly how a FAST exam affects providers' decision making and whether that effect is clinically significant is difficult. None of the studies specifically evaluated whether providers were more likely to cancel a CT scan after a negative versus positive FAST exam. The reasons for cancelling the CT were also not detailed. A reduction in CT scan rates after a negative FAST exam in a patient at moderate risk for IAI is concerning given the FAST exam's low sensitivity. Conversely, bypassing a CT scan in lieu of heading straight to the OR after a positive FAST scan may not always be beneficial to the patient given how many injuries are managed nonoperatively in pediatric patients under current trauma algorithms.

Cost

Only one study evaluated the effect of FAST exams on cost. This randomized control trial showed no statistical difference in overall hospital charges. Adding FAST exam decreased cost by $1180 but with a 95% CI −$6651 to $4291 with $p = 0.67$ [10]. This cost was not further broken down into ED triage costs alone (Table 37.2).

Need for Significant Intervention/Operation

Deducing the effect of FAST exams on rates of laparotomy and other significant interventions is difficult for several reasons. First, studies differed in their definition of "significant intervention," particularly with regard to blood transfusion. Second, all patients who received an intervention after a FAST exam first underwent a CT scan, which obfuscates the importance of the FAST in the decision-making process. This occurred after both positive and negative FAST exams. Third, in the case of laparotomy, whether the injury found truly mandated an operation or could have been managed less invasively is not stated.

With these caveats in mind, the randomized control trial by Holmes showed no significant difference in laparotomy rates between patients who did and did not receive a FAST exam [10]. Nine patients underwent laparotomy, seven of whom had a FAST exam, but all nine underwent a CT scan prior to operation. The prospective observational trial by Calder et al. similarly showed no difference in the rates of transfusion (0.9% no FAST vs 1.7% FAST, $p > 0.05$) or surgery/angiography (1.9% no FAST vs 2.3% FAST, $p > 0.05$) based on FAST exam [11]. Notably, however, in 9/14 (64%) transfusions, 8/16 operations (50%), and 2/3 (66%) angioembolizations, the patients had a negative FAST exam. As in Holmes' study, all patients underwent CT scan prior to intervention. Scaife et al. reported that eight patients in their study required a laparotomy or transfusion, but the number of patients who required intervention without a FAST exam was not stated [13]. Of note, four of the five patients who required a blood transfusion only had a negative FAST [13] (Table 37.2).

Emergency Department Length of Stay

In the single study that evaluated the effect of performing a FAST exam on ED- specific length of stay, there was no significant difference when FAST was added. The decrease of 0.04 h (95% CI -0.47 to 0.40 hours, $p = 0.88$) did not meet the authors' preselected threshold for clinical significance of 1 h [10] (Table 37.2).

Overall Length of Stay

Holmes et al. further evaluated whether performing a FAST exam affected the overall hospitalization length of stay. In their randomized control trial, adding FAST was associated with a significantly shorter length of stay but the difference was only 10.7 hours (95% CI −19.7 to −1.6) [10] (Table 37.2).

Recommendations Based on the Data

The available evidence, although quite varied in methodology and quality, does not support any clear benefits to utilizing FAST exams in hemodynamically stable pediatric blunt trauma patients. As a triage test, the FAST exam does not demonstrate

sufficient sensitivity to be of diagnostic value when negative and does not provide enough diagnostic information to guide management adequately when positive. Perhaps as a consequence of this, the implementation of FAST by trained providers at level 1 pediatric trauma centers is not associated with any decrease in CT scan rates. The effect of FAST use on triage costs and both ED and overall hospitalization stay are also minimal. The lack of any clear benefit and the not insignificant risk of missed injuries or falsely diagnosed injuries argue against the routine implementation of the FAST exam in the evaluation of pediatric blunt trauma patients.

Summary of Recommendations

- Even at level I pediatric trauma centers, FAST scan does not decrease CT utilization rates. Thus, in general application, appropriate implementation of FAST is unlikely to decrease CT rates. The available evidence does not support any clear benefits to utilizing FAST exams in hemodynamically stable pediatric blunt trauma patients (evidence quality moderate; moderate recommendation).
- Based on the low sensitivity of the FAST exam in pediatric patients, confirmatory tests should be obtained following a negative FAST exam. More definitive imaging can help guide clinical management after a positive FAST exam (evidence quality high; strong recommendation).
- The effect of FAST is minimal on triage cost and decreased length of stay. This alone does not offset its other weaknesses (evidence quality moderate; moderate recommendation).

A Personal View of the Data

We agree, based upon the known low sensitivity but high specificity of the FAST exam, it cannot be used as a screening tool to determine further imaging. Rather, it appears to have utility primarily if the result is positive. Based upon a positive FAST, there are very few instances when this does not result in further imaging such as CT scan thus obviating its use in decreasing radiation exposure, hospital cost, or length of ED stay. In the rare instance in blunt trauma when the hemodynamically unstable patient must be emergently taken to surgery without the ability to attain further imaging, positive FAST exam may help guide the surgeon in the decision to start with laparotomy versus thoracotomy. Additionally, if the positive FAST is able to identify the solid organ injured, it is possible that further CT imaging could be avoided as current recommendations for solid organ injury have shifted from radiographic grade to clinical status. Thus, it is possible that the FAST exam may have more of a role in the management of solid organ injury in the future.

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Selective Nonoperative Management of Children with Penetrating Abdominal Trauma

38

Juan E. Sola and Henri R. Ford

Introduction

Trauma is the leading cause of death in patients aged 1–19 years in the United States [1]. Although more than 90% of pediatric trauma patients sustain blunt trauma [2], penetrating injuries account for over 85% of deaths among adolescent patients [3]. Contemporary analyses from our own urban trauma center reveal that 10% of all pediatric trauma patients sustained isolated abdominal injuries and 12% of these required operative intervention [4, 5]. Selective nonoperative management (NOM) of solid organ injuries following blunt abdominal trauma is currently widely accepted as the standard of care in children. It has been shown to be safe while diminishing the morbidity and intensity of care by reducing the number of non-therapeutic laparotomies [6]. However, there is a paucity of data on the applicability of selective NOM for penetrating abdominal trauma in children.

After World War I, mandatory laparotomy became the standard of care for all patients with penetrating abdominal injuries given the nearly 100% mortality rate associated with nonoperative treatment [7]. Shaftan first challenged this practice in 1960 advocating use of clinical parameters as indications for laparotomy in civilian abdominal trauma patients rather than mechanism of injury and surgical dogma. Employing serial physical examination to assess for signs of peritoneal irritation (tenderness, rebound tenderness, and muscle guarding) and careful monitoring of the patient's physiology to exclude shock, laparotomy was avoided in 71 of 103 stab wound (SW) and 4 of 9 gunshot wound (GSW) patients without mortality [8]. Outcomes data accumulated over the last 30 years supporting this approach has led to the creation of modern practice guidelines from the main US trauma societies for

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the NOM of penetrating trauma in stable adult patients without signs of peritonitis [9–11]. However, no standard management guidelines for selective NOM exist for pediatric patients suffering from penetrating abdominal trauma. In this chapter, we review and analyze the available published literature on selective NOM of children sustaining penetrating abdominal trauma with specific emphasis on selection criteria, management principles, safety, and associated efficacy.

Search Strategy

We performed a systematic search of the literature indexed by the Embase and MEDLINE databases. The Embase database was searched employing the PICO search strategy as outlined in Table 38.1. The search terms for our population of interest were patients with "abdominal penetrating trauma" and its 10 associated synonyms while the search terms for intervention were "nonoperative treatment" with 8 associated synonyms. The MEDLINE database was subsequently queried with the PubMed search engine utilizing the terms "abdomen, abdominal, penetrating, injuries, trauma, wounds and injuries, wounds, injuries, nonoperative, therapy, treatment, and therapeutics" (see Appendix).

The literature search was limited to all peer-reviewed articles published in English language journals over the last 20 years from January 1, 1999 to November 30, 2019. All articles were reviewed and selected for inclusion only if participants included pediatric patients who had sustained penetrating abdominal trauma managed non-operatively. Included articles were classified as to quality of the data reported according to the GRADE system.

Results

Review of the Literature

A total of 113 full-text articles were identified and reviewed. Four retrospective studies met our inclusion criteria and were selected for analysis of selective NOM of penetrating abdominal trauma in children (Table 38.2). Three of the studies were single institution retrospective case series from Turkey [12–14] published between 2002 and 2013 with a total of 192 patients (87% male, 78% SW), almost half of which had selective NOM. In addition, an analysis of the National Trauma Data Bank (NTDB) from the United States published in 2018 examined over 3000

Table 38.1 PICO terms used for search of Embase database

Patients	Intervention	Comparator	Outcomes
Abdominal penetrating trauma (10 synonyms)	Nonoperative treatment (8 synonyms)	Surgery (30 synonyms)	Surgery (30 synonyms), treatment failure (3 synonyms), mortality (3 synonyms)

Table 38.2 Summary data for included studies

Study	GRADE	Patients (*n*)		Operation (*n*)				NOM (*n*)			Deaths
		SW	GSW	SW	GSW	Neg	Comps	SW	GSW	Failure	
Ozturk, 2002	Low quality	59	0	44	0	12	4	15	0	1	0
Cigdem, 2009	Low quality	60	30	19	20	6	5	41	10	2	0
Boleken, 2013	Low quality	31	12	11	7	11	0	20	5	0	0
Sakamoto, 2018	Low quality	852	2153	545	1845	NR	NR	307	308	175[a]	1

Abbreviations: *SW* stab wound, *GSW* gunshot wound, *Neg* negative laparotomy, *Comps* postoperative complications, *NOM* nonoperative management, *NR* not reported
[a]50 SW and 125 GSW NOM failures

pediatric patients who sustained penetrating abdominal trauma with 21% managed nonoperatively [15]. Given their retrospective design, all studies were classified as reporting low quality GRADE system data.

Ozturk [12] in 2002 reported 59 patients (56 males), 3–14 years old, who sustained SW with peritoneal penetration presenting at their university hospital between 1983 and 2001. Median time between injury and admission was 3 h (range 1–8 h). Immediate laparotomy was performed in 44 patients who on presentation had signs of peritonitis (n = 26), evisceration of omentum/small intestine [16], or pneumoperitoneum on radiography [17]. Laparotomy was negative in 12 patients for a nontherapeutic rate of 27% and associated with a 9% complication rate. In contrast 15 patients with confirmed peritoneal penetration by diagnostic peritoneal lavage (DPL) or local wound exploration (LWE), and normal clinical and hemodynamic findings were observed. One of these patients subsequently developed signs of an acute abdomen and had a laparotomy. There were no deaths in their cohort.

In a 2009 follow up study from the same center, Cigdem [13] reported 90 patients (76 males), 1–16 years of age, who sustained SW (60) and GSW (30) through the peritoneum from 2003 to 2008. Time interval between injury and admission ranged from 1 to 10 h (mean 3 h). Over 50% of patients (41 SW, 10 GSW) without hemodynamic instability, peritonitis, or imaging suggestive of hollow viscus injury had selective NOM. Two of these patients required subsequent laparotomy following 20 and 24 h of observation. One patient had a perforation in the ileum while the other had a negative laparotomy. Of the 39 patients who underwent initial operative management (19 SW, 20 GSW), 6 SW patients had no organ injury for a nontherapeutic laparotomy rate of 32% for SW injuries. The operative complication rate was 5% but there were no deaths reported in this series.

Boleken [14] published a single center experience with penetrating thoracic and abdominal trauma in children admitted from 2006 to 2012 to a medical center serving a developing rural province. There were 43 abdominal (31 SW, 12 GSW) injuries. Most patients were male (81%) and ranged from 3 to 16 years in age. Eighteen patients with hemodynamic instability, signs of peritonitis, evisceration through abdominal defect, or radiological evidence of hollow viscus injury underwent

laparotomy. No injuries were found in 11 of these patients for a nontherapeutic laparotomy rate of 61%. Twenty-five patients (20 SW, 5 GSW) had selective NOM without need for delayed laparotomy. The authors reported no associated morbidity or mortality in their case series.

Most recently, Sakamoto [15] reported an 8-year analysis (2007–2014) of patients less than 19 years of age, registered in the NTDB, who sustained penetrating solid organ injuries. The authors defined NOM as those patients who had no operative intervention for abdominal injuries within 4 h after trauma center arrival. Failure of conservative management was defined as any abdominal operations, excluding angiography and angioembolization, performed greater than 4 h after arrival. Analysis of 3005 patients (89% male, 72% GSW) revealed that 615 (21%) patients met the definition for NOM, which was associated with an overall 72% success rate. Patients who sustained SW were more likely to undergo NOM (36%) than those who sustained GSW injuries (14%). Success rates for NOM were highest for liver injuries (81%), and SW injuries (84% vs 59% for GSW, $p < 0.001$), independent of age group. Associated hollow viscus injury was identified in 67% of the entire cohort and accounted for 84% of NOM failures. Only 1 patient died after NOM for a mortality rate of 0.2% and 0.6% for failed conservative management.

Recommendations Based on the Data

Criteria for Selective NOM

In the four studies reviewed, absence of peritonitis and hemodynamic stability were consistently employed to identify pediatric candidates for NOM following penetrating abdominal trauma. Peritonitis is a subjective finding largely dependent on the experience of the clinician making the assessment [17]. In addition, injured children are particularly challenging and frequently uncooperative during physical examination. If available, a pediatric surgeon should be involved as early as possible in the management of these patients. Regardless, it may be difficult to distinguish true peritoneal signs from tenderness related to the penetrating wound that violates the peritoneum, which may or may not be associated with hollow viscus injury. Combining Ozturk and Cigdem's reported data, 49/56 (88%) children with signs of peritonitis had a therapeutic laparotomy principally identifying a hollow viscus injury as the source.

Sakamoto's analysis of the US nationwide trauma database showed that hypotension was a significant independent predictor (OR: 2.94, $p = 0.002$) for laparotomy in pediatric patients with penetrating abdominal trauma. However, an elevated shock index pediatric age-adjusted (SIPA) was not an independent predictor for immediate laparotomy or NOM failure. However, it is universally accepted that immediate laparotomy is warranted for all pediatric patients presenting with hemodynamic instability following penetrating abdominal trauma as this indicates significant hemorrhage requiring surgical control from a vascular, mesenteric, or solid organ injury.

Evisceration as an indication for immediate laparotomy continues to be controversial even in the current age of selective NOM. Our review found that evisceration was used as an indication for laparotomy in the three case series from Turkey. In 23 children with eviscerated omentum or intestine, organ injuries were detected in 43%. For all practical purposes, children presenting with evisceration will require a minimum operative repair under anesthesia of the abdominal wall hernia. In stable patients with a small wound, we recommend laparoscopy for abdominal exploration prior to full laparotomy (see subsequent discussion on laparoscopy).

Lastly, other exclusions for selective NOM include [1] inability to sequentially assess the abdomen due to associated injuries (head, spinal cord, and other extra-abdominal regions requiring surgery), or [2] impalement through the abdomen.

NOM of the Stable Pediatric Patient

Close monitoring, preferably in an intensive care unit setting, and serial abdominal examinations every 4–6 h ideally by the same surgical team are integral components of NOM of penetrating abdominal injuries in children. A complete blood count should be initially obtained every 12 h to follow the hemoglobin level and white blood cell count. We do not recommend blood transfusion in hemodynamically stable patients unless hemoglobin drops below 7 mg/dL. A rising white blood cell count should raise concerns for a hollow viscus injury. Diet should not be introduced until the surgeon is confident that no surgical intervention is required typically after 24–48 h of observation, and return of bowel function is confirmed.

Although Ozturk's report used LWE and DPL to confirm peritoneal penetration in patients treated from 1983 to 2001 at their institution, present care standards at most modern trauma centers would require sedation or general anesthesia for this procedure to be performed in children. A limitation of both of these diagnostic procedures is that while they identify violation of the peritoneum they fail to identify organ injuries and specifically those that require laparotomy.

In patients without a clinical indication for laparotomy, several imaging modalities can be used to help guide management. Plain radiography of the chest, abdomen, and pelvis are routinely obtained on arrival and can identify pneumoperitoneum as well as the trajectory and number of bullets in GSW victims. Pneumoperitoneum is best detected on an upright chest radiograph and usually indicates the presence of a hollow viscus injury requiring abdominal exploration. In our review, Ozturk reported that only 6 of 16 pediatric SW patients with pneumoperitoneum had an associated abdominal organ injury. The authors commented that, in addition to the abdominal wound, a chest wound with an associated diaphragmatic injury could account for the peritoneal air.

In our review, Cigdem performed detailed abdominal sonography on 51 hemodynamically stable patients treated with NOM finding no significant injury in 80% of patients. However, no ultrasound findings were reported for the two patients who subsequently required laparotomy. Boleken also used ultrasonography in 55% of 43 pediatric patients with penetrating abdominal trauma but no data was reported on

how imaging results guided management. Focused abdominal sonography for trauma (FAST) or ultrasonography can be used instead of LWE or DPL in pediatric patients to identify patients with hemoperitoneum. When present, this finding confirms violation of the peritoneum and, in those patients with a thoracic penetrating injury, it mandates abdominal exploration for a presumed diaphragmatic injury.

Of the three case series included in this review, only Boleken routinely employed abdominal computed tomography (CT) in 62% of 43 pediatric patients with abdominal penetrating injuries. However, no data was presented on the sensitivity and specificity of this imaging modality in detecting intra-abdominal injuries. Modern abdominal CT scans utilizing fine cuts are able to reconstruct missile trajectory, which is vital in patients with tangential GSW in order to avoid nontherapeutic laparotomy. In addition, a recent meta-analysis on the accuracy of abdominal CT in 575 adult patients presenting with anterior abdominal stab wounds found that nearly 10% of patients with a negative study required a therapeutic laparotomy and 59% of these missed injuries involved mainly the small intestine but also the colon and stomach [18]. Despite this limited applicability and low sensitivity, both the Eastern Association for the Surgery of Trauma [9] and Western Trauma Association [10, 11] guidelines include abdominal CT as part of the initial screening studies for patients selected for NOM. If present, CT findings suggestive of hollow viscus injury such as pneumoperitoneum, extravasation of oral or rectal contrast, edematous bowel wall, or mesenteric hematoma should minimize operative delay.

The role of laparoscopy, albeit controversial in adult trauma patients, has value in the pediatric population where LWE and DPL are not performed. Laparoscopy reliably identifies peritoneal penetration, hemoperitoneum, and diaphragmatic injury. We recommend laparoscopy prior to laparotomy in patients with questionable physical examination findings, or inconclusive diagnostic imaging, and especially in those with associated injuries resulting in an unreliable physical examination. Interestingly in Sakamoto's NTDB analysis, diagnostic laparoscopy was performed in less than 3% of nearly 2400 pediatric patients undergoing immediate operation and only in 14 of 175 patients who failed NOM. Injuries to the posterior wall of the stomach, mesenteric border of the small bowel, or retroperitoneal colon are difficult to identify via laparoscopy and a low threshold for laparotomy should be used once intra-abdominal injury is confirmed.

Safety and Efficacy of Selective NOM for Pediatric Penetrating Abdominal Trauma

The three studies from Turkey report a total of 192 patients sustaining predominantly SW injuries (78%), with almost half (91) managed nonoperatively. Pooling their reported data, laparotomy was associated with a 29% nontherapeutic rate and a 9% complication rate. In contrast, the failure rate for selective NOM was 3.3% with no associated mortality. These excellent results must be weighed in light of potential patient selection due to prolonged transport times of up to 10 h reported in the above studies. Patients with serious injuries sustained in settings geographically

remote from the medical center may have died at the scene of injury or during prolonged transport.

By comparison, the majority of 3005 pediatric patients in the NTDB sustained GSW (72%) and NOM was associated with a nine-fold higher failure rate of 28% but a similarly low 0.2% mortality rate. For pediatric abdominal SW, the NOM failure rate of 16% was similar to the 21% reported in adult case series [16, 19]. However, the NOM failure rate for pediatric abdominal GSW in the NTDB was 41% at modern American trauma centers. This partly may be explained by the high prevalence of associated hollow viscus injuries (67%) in this pediatric patient cohort predominantly sustaining GSW injuries. GSW accounted for over 70% of NOM failures, which were due to hollow viscus injuries in 84% of cases. A 40% failure rate is significantly higher than the 8.4% NOM failure rate recently reported in 215 adult patients who sustained abdominal GSW [20]. Thus, more stringent selection criteria are needed for NOM in pediatric patients with abdominal GSW, in contrast to adults.

Review of Recommendations

- Pediatric patients who are hemodynamically stable, without signs of generalized peritonitis or evisceration, and who have a reliable clinical examination are candidates for selective NOM in centers with pediatric surgical expertise (evidence quality high; strong recommendation).
- Pediatric patients selected for NOM should undergo diagnostic imaging to identify peritoneal penetration and associated intra-abdominal injuries, although negative studies do not exclude a hollow viscus injury (evidence quality high; strong recommendation).
- Diagnostic laparoscopy should be utilized prior to laparotomy in patients with questionable findings or unreliable examination (evidence quality moderate; weak recommendation).
- Selective NOM is a safe and efficacious option for pediatric patients with abdominal SW (evidence quality high; strong recommendation).
- Selective NOM should be utilized only in pediatric patients with CT-proven tangential and extra-peritoneal abdominal GSW (evidence quality high; strong recommendation).

A Personal View of the Data

We conclude based on limited, low data quality retrospective and epidemiologic studies that selective NOM in children sustaining penetrating abdominal trauma is associated with low mortality with only 1 death reported in 178 NOM failures. In addition, selective NOM is efficacious in children who sustain abdominal SW, but has limited success following GSW injuries. Cooperative multicenter prospective

randomized control trials are needed to generate higher quality data to identify variables associated with NOM failure.

In our Level 1 urban trauma center, we commonly use selective NOM in pediatric abdominal SW and tangential GSW injuries, but rarely if ever in a nontangential GSW injured child. Diagnostic laparoscopy is initially performed in hemodynamically stable patients requiring operative intervention in order to confirm peritoneal penetration or evidence of intra-abdominal injury prior to laparotomy.

Appendix

MEDLINE database PubMed search terms: ("abdomen [MeSH terms] OR "abdomen" [All Fields] OR "abdominal" [All Fields] AND penetrating [All Fields] AND ("injuries" [Subheading] OR "injuries" [All Fields] OR "trauma" [All Fields] OR "wounds and injuries" [MeSH terms] OR "wounds" [All Fields] AND "injuries" [All Fields]) OR "wounds and injuries" [All Fields] AND nonoperative [All Fields] AND ("therapy" [Subheading] OR "therapy" [All Fields] OR treatment" [All Fields] OR "therapeutics" [MeSH Terms] OR "therapeutics" [All Fields]).

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39

Are Outcomes Equivalent for Injured Children Treated at Pediatric Versus Adult Trauma Centers, and What Are the Implications with Respect to the Design of Optimal Trauma Systems?

Mark B. Slidell

Introduction

Injury has been the leading cause of death and disability in childhood for many decades and children account for approximately 25% of all traumatic injuries [1]. An injured child may end up receiving treatment at a dedicated pediatric trauma center (PTC), an adult trauma center (ATC), or what is variably referred to as a mixed trauma center (MTC) or an adult trauma center with additional qualifications (ATC-AQ). While most State guidelines are either the same or similar to those of the ACS-COT, trauma center designation criteria vary from state-to-state, and due to the relative scarcity of PTCs, it is not uncommon for children to receive their care at an ATC or even a non-trauma center. The ACS-COT acknowledges that trauma care for injured children will not always occur in a pediatric center, but it "may be optimally provided in the environment of a children's hospital with a demonstrated commitment to trauma care." [2]

The ACS has been providing trauma center designation and verification since the 1970s, but it was not until relatively recently that the impact of those trauma centers was objectively measured and quantified. The seemingly obvious question of whether adult trauma centers save lives was evaluated in a landmark paper by Dr. Ellen MacKenzie, et al. in 2006 where they reported "that the risk of death is significantly lower when care is provided in a trauma center than in a non-trauma center and argue for continued efforts at regionalization." [3] This "proof" that trauma centers save lives seems self-evident, but this was the first objective measurement of

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the overall benefits of adult trauma centers. Their findings were soon replicated in a similar study looking at pediatric trauma centers, which found State-to-State disparities in outcomes with lower statewide pediatric mortality rates in States with higher-level ACS-verified pediatric trauma centers. Like the adult trauma study before it, this paper by Notrica et al., confirmed the value of pediatric trauma centers and ACS-verification.

Despite the reported benefits of treating injured children in a PTC, geography and the availability of specialized pediatric centers plays a role in where an injured child ends up receiving care. A recent U.S. Government Accountability Office report found that of the 73.7 million children in the United States, 31.8 million (43%) of them do not live within 30 miles of a "high-level" PTC [4]. This is consistent with previous studies finding that approximately 45% of injured children are treated at non-trauma centers [5]. These numbers are sobering when one considers that there is considerable evidence that children receiving specialized care for their injuries have better outcomes. The study by Notrica et al. had shown the correlation between ACS-verified State pediatric trauma centers and statewide mortality rates [6]. This study and others confirmed that the overall outcomes for injured children were better when children receive specialized, pediatric-centric care for their injuries [7]. If nearly half of the children in the United States do not have access to this highest level of pediatric trauma care, then that disparity in access to care is concerning.

The question we will consider is whether it matters if injured children receive treatment at pediatric or adult trauma centers, and is this true for all injury types? Would it be better for an injured child to be treated at the nearest trauma center even if that is an adult trauma center, or should they be transported to a PTC, even if that means a significantly longer transport time? In essence, what are the outcomes for children treated in adult trauma centers and are they adequate and equivalent to outcomes at a pediatric center?

Search Strategy

A search of English language publications from 2005 to 2020 was performed to identify articles to answer the question of "what are the outcomes for children treated at an adult trauma center?" Databases searched were PubMed and Cochrane Evidence Based Medicine. Terms used in our search included Pediatric trauma center, Adult trauma center, mixed trauma center, adult trauma center additional qualifications, outcomes, mortality. The American College of Surgeons defines a pediatric trauma patient as anyone under the age of 15 years. Only 20% of States use that definition, so we reviewed articles in which patients up to the age of 18 were considered children.

P (Patients)	*I (Intervention)*	*C (Comparator)*	*O (Outcomes)*
Infants, children, and adolescents suffering from traumatic injury	*Traumatic resuscitation or surgery*	*Adult trauma surgeons, and pediatric surgeons or pediatric trauma surgeons*	*Mortality, surgical complications, long-term functional outcomes, reduced radiation*

Results

There are a number of papers evaluating outcomes for traumatically injured children treated at ATCs and PTCs; however, many of these are from single trauma centers or only evaluate data from a single State. Given the heterogeneity of State trauma systems and especially the tremendous variability in the age chosen to categorize a trauma patient as a child or an adult, it can be difficult to extrapolate these results nationally. There are however a number of studies attempting to address this question, and overall, children treated at a PTC appear to have equivalent or superior risk-adjusted mortality rates compared to those treated at an ATC. Unfortunately, there remains a paucity of data on other outcomes measures such as length of stay, costs, and long-term morbidity for PTCs versus ATCs. For the sake of this review, we will focus primarily on the outcome measure of mortality.

The initial studies looking at differences in outcomes for injured children treated at ATCs and PTCs were mostly single-center and state-based studies from a decade or more ago. A review of the trauma literature up through 2009 concluded that there was insufficient evidence to declare that either ATC or PTCs had superior outcomes in the treatment of severely injured children [8]. More recent studies have moved away from single-center reports and have utilized large administrative databases such as the NTDB to look into this question. These recent studies have consistently found that children treated at PTCs have lower mortality rates, and a number of other improvements in outcomes such as more success with non-operative management of solid organ injuries and improved overall long-term functional outcomes.

While more recent studies have shown that children treated at PTCs have a lower mortality risk vs. ATCs and other facilities treating injured children, there are still some studies that have found no difference between the different types of trauma centers [8, 9]. One of the challenges is that the most consistently tracked outcome measure in trauma databases is patient mortality, but mortality is a problematic outcome measure when comparing pediatric and adult patients. Overall mortality is an infrequent event in children and it is lower in severely injured children compared with adult patients, making it a slightly limited outcome measure.

Another challenge is the inconsistent definition of a pediatric versus adult patient in the studies on this subject as well as the actual trauma center designation at the State level. Only about 20% of States follow the ACS-COT definition of pediatric trauma patients consisting of children <15 years of age, while another 20% use 16 years as the cutoff and about 20% use a cut off of 18 years old. The same holds true in the papers on this topic with the majority focusing on children 18 and under, but there were still several studies using the lower ACS-COT age cutoff of ≤14 years in their research. Recognizing these issues, we will attempt to evaluate the evidence at hand.

One question is whether a mixed adult and pediatric trauma center might successfully stand in for a PTC in regions where a PTC is not available. Some adult trauma centers achieve designation as an ATC with added qualifications in pediatrics (ATC-AQ) or what is also referred to as a mixed trauma center (MTC). A study using the National Trauma Data Base (NTDB) looked at children seen in an ATC-AQ

instead of a stand-alone ATC and concluded that improved overall survival was associated with pediatric trauma patients treated at an ATC-AQ versus an ATC [10]. While encouraging that outcomes at an ATC-AQ were superior to centers that did not pursue the additional qualifications to care for injured children, these centers still do not outperform PTCs.

One of the earliest papers addressing this question looked at mortality rates for Florida trauma patients treated in PTCs versus ATCs and mixed trauma centers (MTC) caring for both pediatric and adult patients in the same center. They found a lower risk of mortality for children <18 years of age who were cared for in PTC instead of ATCs or MTCs with an approximately 8% reduction in the likelihood of mortality among pediatric trauma patients treated PTCs in Florida [11]. In a separate study comparing mortality rates for children treated at a PTC instead of either an ATC or MTC. They found that injured children treated at ATCs and MTCs had higher in-hospital mortality compared with those treated at PTCs. This association was strongest in younger children but was also present in the most severely injured children. The overall crude mortality rates documented were 2.3% for children treated at ATCs, 1.8% for children treated at MTCs, and only 0.6% for children treated at PTCs [12]. This suggests that these ATC-AQs or MTCs could be a reasonable surrogate for a PTC in areas without high-level pediatric centers within a reasonable geographic distance.

Much like the findings seen in many other surgical specialties, there also seems to be a volume-outcomes relationship for trauma care. A recent meta-analysis of articles on the volume-outcome relationship in trauma centers found a "modest association between high-volume centers and lower mortality in severely injured patients." [13] This volume-outcome association appears to be even stronger when one looks at the relationship between trauma center volumes and pediatric trauma outcomes in an adult trauma center. Miyata et al. compared outcomes for severely injured children treated at adult trauma centers with very different annual case volumes of pediatric patients. When the ATCs were stratified into four groups based on median annual pediatric trauma volumes, it was clear that the highest volume centers had lower pediatric mortality rates. When compared to the lowest volume centers, there was a nearly 50% reduction in mortality rates for the highest volumes centers which cared for a median of 43 injured children per year (mortality OR 0.495, 95% confidence interval 0.312–0.785). There was a similar reduction in mortality for the youngest injured patients with children <10 years of age having a 51% reduction in the odds of death (OR mortality 0.491 0.310 ~ 0.777) [14].

Given that the association between type of trauma center and mortality rates was strongest for the youngest children, one could surmise that adolescents might have equivalent outcomes at either an adult or a pediatric trauma center. Adolescent patients are typically the same size as adult patients and essentially have adult physiology. A very well-done study using NTDB data looked at the trauma center type and mortality rates among injured adolescents aged 15–19 years in the United States. Once again, the mortality rates for adolescents treated at ATCs was significantly higher (3.2%) than MTCs (3.5%) or PTCs (0.4%). The adjusted odds ratio (OR) for mortality was also higher at ATCs (OR, 4.19; 95% CI, 1.30–13.51) and

MTCs (OR, 6.68; 95% CI, 2.03–21.99) compared with PTCs [15]. This paper controlled for factors such as mechanism of injury and injury severity, but it was unable to account for potential confounders that could perhaps explain these disparities. For example, the patients transferred into pediatric centers from other hospitals may have been more stable than those pediatric patients presenting directly to adult hospitals. Differences in pediatric patient triage patterns and in treatment practices might explain some of these findings.

If there is one portion of the pediatric population which seems most likely to benefit from the expertise of an adult trauma center, it would be those children with penetrating injuries. This is a far more common mechanism of injury in adult trauma centers. The adult trauma surgeons are more likely to have a significant level of efficiency at dealing with these types of injuries and one would expect them to have better outcomes than would be seen for these patients in a pediatric trauma center. A recent study evaluated this specific question in an attempt to determine whether the "trauma experts" or the "pediatric experts" would have better outcomes for pediatric penetrating injuries. They ended up finding equivalent survival outcomes whether the child was treated at a PTC or an ATC. They also noted that the younger pediatric patients may have superior functional outcomes when treated at PTCs [16]. This is a slightly surprising outcome, but it suggests that the most severely injured adolescent pediatric patients might have equivalent outcomes at an adult trauma center, and that there might be a way to triage those patients towards receiving their care at an adult center if it were significantly closer than a PTC.

If we accept that children in general have better outcomes when they are able to receive care at a PTC, then we should understand what access to that care looks like. Unfortunately, access to either a PTC or an ATC within the "Golden Hour" after acute injury is inconsistent across the United States with over 17.4 million children unable to access a high-level pediatric trauma center within the traditional golden hour after injury by air or ground transportation [17]. If this is the case, then we must also look more closely at outcomes for injured children treated at ATCs and discuss whether it better for a child to be treated at the nearest trauma center even if that is an adult trauma center, or whether they ought to be transported to a PTC, even if that means a significantly longer transport time?

While mortality rate is the most common outcome measure compared in these studies, there are a number of other differences between adult and pediatric trauma centers that have been observed, and should be accounted for in decisions regarding the composition of regional trauma systems. For example, non-operative treatment of solid organ injuries after blunt abdominal trauma is more successfully employed in PTCs, and splenic preservation rates usually higher while transfusion rates are typically much lower in PTCs [18, 19]. Other findings include more judicious use of radiation in imaging injured children when they are managed in a PTC following the principles of "As Low As (is) Reasonably Achievable" (ALARA) safety principles for imaging patients [20, 21]. These and other differences seen in orthopedic and neurosurgical outcomes should also be weighed in these decisions.

Recommendations Based on the Data

Overall, the higher quality contemporary studies support the argument that injured children have lower mortality rates when treated in pediatric trauma centers. The unfortunate reality is that 31.8 million (43%) of children in the United States do not live within 30 miles of a "high-level" PTC, and so nearly half of the severely injured children are cared for in ATCs or non-trauma centers [4]. In areas where the geographic distance to a PTC is too great, an injured child should always be triaged to the closest ATC-AQ or ATC instead of a medical center without any formal trauma center designation. Appropriate triage systems are needed to ensure that severely injured children are treated in PTC when possible. It is also clear that the younger the injured patient, the greater the benefit of a PTC over an ATC. There is inadequate research to recommend triage of the most severely injured adolescents to high-volume ATCs, but it would seem irresponsible to attempt to triage an unstable pediatric trauma patient to a specialized PTC at a great geographic distance if there is a qualified ATC significantly closer.

Summary of Recommendations

Rank Preferences

- Injured children appear to have improved outcomes when treated at pediatric trauma centers as compared to those treated at adult trauma centers. This is particularly true of younger children <12 years of age. Severely injured children should be triaged to specialized pediatric trauma centers whenever possible to do so without jeopardizing the well-being of the child due to excessive transport times and distances (evidence quality moderate; moderate recommendation).
- In the event a pediatric trauma center is not in close proximity to an injured child, they should be preferentially triaged to adult trauma centers with additional qualifications in the care of injured children (evidence quality moderate; moderate recommendation).
- Triage to an adult trauma center is preferential to triage to a center without any trauma accreditation (evidence quality moderate).

A Personal View of the Data

Injured children have different anatomic, physiologic, and psychological characteristics than adults and necessarily require specialized care. Pediatric trauma centers are best able to provide this care by ensuring that specialized resources such as appropriately sized equipment is available and that weight-based dosages of medications are correctly administered by personnel with specialized pediatric training. It is unfortunate that there are simply not enough pediatric trauma centers in the United States to ensure access for every injured child. While I believe the best place

for an injured child is in a pediatric trauma center with either ACS-COT or State accreditation, this is not always possible. The number of Level 1 and Level 2 PTCs is ultimately constrained by the fact that there are only about 1000 board certified Pediatric Surgeons in the USA, and the national supply of pediatric sub-specialists such as neurosurgeons, orthopedists, anesthesiologists, and radiologists is also constrained. The Institute of Medicine has long recognized a, "crisis in the emergency care of children, secondary to a general lack of equipment, facilities, and personnel." [22] There remains fragmentation of the many components of pediatric emergency care services as the separate missions of EMS, trauma centers, and public health agencies are not always sufficiently aligned in the coordination of care for injured children. In addition, the specialized care and resources required for injured children are not equally distributed across the country, and access to the highest levels of trauma care can be uneven or lacking in some regions.

In addition, there is significant variability from state-to-state in how trauma centers achieve accreditation. While national guidelines from the American College of Surgeons—Committee on Trauma would seem to be the best guidelines to follow, not all states and counties use these. The reality is that trauma triage and transfer guidelines lack uniformity across the States, and in some locations, the guidelines may vary on a county-by-county level. One challenge in evaluating the studies referenced above is that there is significant State-to-State variability in definition of the age at which a child is considered a "pediatric" trauma patient. There is no uniformly accepted age cut-off for a pediatric trauma patient. In fact, the ACS-COT age cutoff for pediatric trauma patients is ≤14 years and this is only followed in 22.6% of the nation's trauma centers. Most of the remaining trauma systems variably choose ≥16 years (21.6%), ≥17 years (9.9%), or ≥ 18 years (12%) [23]. This further complicates any analysis of national outcomes in pediatric trauma centers given that there remain discrepancies in the definition of a pediatric patient.

The limited number of PTCs precludes the possibility that all injured children will be treated in PTCs, and so it is important to determine which children might most benefit from this somewhat scarce resource and develop appropriate triage systems. While I strongly advocate that all injured children should have unfettered access to the high level of specialized pediatric trauma care found in pediatric trauma centers, there could be subsets of patients who are actually better served in adult trauma centers. For example, adolescents who are severely injured due to penetrating trauma appear to have equivalent mortality outcomes at ATCs and PTCs [17]. It is difficult to believe that immediate access to an ATC within the "Golden Hour" for a penetrating trauma injury would not result in superior outcomes for pediatric patients. This is especially true if that child would require a delay in treatment to reach a pediatric trauma center. It would be difficult, but not impossible, to create a regional trauma system with "carve outs" for certain mechanisms of injury such a hemodynamically unstable penetrating trauma. In fact, this might be the best solution in many regional trauma systems if the nearest PTC is at a greater geographic distance than the nearest Level 1 ATC. Close collaboration between ATCs and regional PTCs could potentially bridge any remaining differences in outcomes for injured children treated in ATCs. There constrained supply of pediatric surgeons

and pediatric trauma centers in the United States, and the allocation of resources within a trauma system must take this into account when attempting to design the optimal trauma system for treating injured children. An optimal triage system would account for these factors and might consider differential triage of injured children based upon factors such as hemodynamic instability and mechanism of injury.

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Index

A
ABC approach, 5
ABCD sequence, 9
Abdominal gunshot wounds (GSWs)
  CT, 208, 209
  imaging, 211, 212
  morbidity, 207
  observation period, 212–214
  patient selection, 210, 211
  penetrating abdominal injuries, 207
  search strategy, 208, 209
  SNOM, 214, 215
ACS-verified State pediatric trauma centers, 442
Acute Respiratory Distress Syndrome (ARDS), 173, 255, 256
Adult trauma center (ATC), 441, 446
  golden hour, 445, 447
  mortality rates, 443–445
  outcomes measures, 443
  single-center and state-based studies, 443
  superior risk-adjusted mortality rates, 443
Adult trauma center with additional qualifications (ATC-AQ), 441, 446
Advanced Cardiac Life Support (ACLS), 5, 274
Advanced Trauma Life Support (ATLS) guidelines, 3, 140
Advisory Committee on Immunization Practices (ACIP), 117
Air medical transport/trauma, 26
American Association for the Surgery of Trauma (AAST), 6, 289, 315
American College of Emergency Physicians (ACEP), 47
American College of Surgeons – Committee on Trauma (ACS-COT), 47, 48, 443, 447
American Psychological Association, 350
Aminoglycosides in combination with clindamycin, 111
Ampicillin/sulbactam, 111
Angioembolization, 143–144, 147
Angiography, 144, 146
Anterior pelvic bleeding, 141
Antibiotic prophylaxis, 101
Antibiotic regimen in patients with complicated intra-abdominal infection, 107
Antibiotic regimens for cIAI, 111
Antibiotic selection, 94
Antibiotics prophylaxis after penetrating colon injuries, 99–102
Antibiotic therapy in complicated intra-abdominal infection, 107
Aortic clamping, coupled with emergency surgery to control hemorrhage, 45
Arterial angioembolization (AAE), 140, 144–146, 149
Arterial bleeding, 141
As Low As (is) Reasonably Achievable (ALARA) safety principles, 445

B
Basic Endovascular Skills for Trauma (BEST course), 47
Basic Life Support (BLS), 5
Big Brothers Big Sisters (BBBS) program, 376
Bilateral non-selective embolization of the internal iliac arteries, 140
Blunt cardiac injury (BCI)
  FAST, 272, 273
  polytrauma, 276
  presentations and clinical manifestations, 267

K. Wilson, S. O. Rogers (eds.), *Difficult Decisions in Trauma Surgery*, Difficult Decisions in Surgery: An Evidence-Based Approach,
https://doi.org/10.1007/978-3-030-81667-4

Blunt cardiac injury (BCI) (cont.)
recommendations, 275
screening, 268–272
search strategy, 268
testing, 276
treatment, 273, 274
Blunt cerebrovascular injury (BCVI)
antiplatelet therapy, 194
causes, 189
recommendations, 193
screening tools
computed tomography angiography, 191
diagnosis, 191, 192
duplex ultrasound, 191
four vessel arteriography, 191
inclusion criteria, 190
Memphis, 190
search strategy, 189
systematic method, 194
treatment, 192, 193
Blunt trauma, 128
Blunt trauma pan scan, 129
Brain-dead donors, *see* Donation after cardiac death (DCD) donors
Bronfenbrenner's model, 370
Butty Socioecological Model, 368

C
Cardiac contusion, 268, 274
Cardiopulmonary resuscitation (CPR), 5, 343
Carotid artery, 189, 192
Cefepime, 111
Cervical spine injury
clinical evidence, 156, 159
clinical examination, 155
distracting injuries, 160
identification, 155
literature review process, 156–158
PICO, 156
recommendations, 159, 160
cIAI antibiotic therapy, 106
Civilian trauma community in both the pre-hospital and in-hospital phases of care, 4
2020 Clinical Practice Guidelines (CPG), 48
Coagulopathy, 13, 18, 21
Cochrane Evidence Based Medicine, 26
Colon injuries, 100–102
Committee on Trauma (COT), 243
Common femoral artery (CFA), 144
Community-acquired (CA-IAI), 105
Compassion fatigue, 350
Complex extremity wounds in goats, 67
Complicated intra-abdominal infections (cIAI), 105–107, 111–114
Component therapy for civilian trauma patients, 15

D
Damage-control laparotomy (DCL) in a multi-trauma scenario, 102
Damage control resuscitation, 186
Damage control surgery, 77
Decompressive craniectomy (DC), 184, 185
Decompressive laparotomy (DL), 184
Distal SAE, 119
Distracting injuries (DI), 155, 156, 159
Donation after cardiac death (DCD) donors
controlled DCD, 326
cost of resuscitation, 334
dead-donor rule, 336
ECMO support, 332
ED thoracotomy, 332
ethical and logistical challenges, 326
GRADE approach, 326, 327, 333–335
Institute of Medicine guidelines, 326
literature search strategy, 327
LUCAS system, 334
Maastricht Classification, 326
massive preparatory effort, 334
medical and ethical literature, 336
neurologic criteria, 325
organ procurement organization (OPO), 332
Organ Procurement Transplant Network, 335
PICO, 326, 327
resuscitative efforts, 336
search strategy, 327
simultaneous and irreversible findings, 325
uncontrolled DCD, 326, 333, 334
UNOS registry, 333
Duodenal hematoma, 221
Duodenal injury
AAST OIS, 220
duodenal hematoma, 221
historical procedures, 219
Berne's diverticulization, 222
drain placement, 223
enteric feeding, 223, 224
pancreaticoduodenectomy, 223
primary repair, 222
pyloric exclusion, 222
recommendations, 224
surveillance, 224
triple tube decompression technique, 222
imaging, 221
incidence, 219

laparotomy, 224
search strategy, 220, 221
DURAPOP trial, 112, 113
Duration of antibiotic therapy for cIAI, 112

E
Eastern Association for the Surgery of Trauma (EAST), 48, 164, 292, 315, 351
EAST Practice Management Guidelines Work Group, 95
ECF formation after trauma laparotomy, 75
Eisenstein's *New England Journal of Medicine*, 356
Embolic agents, 145
Embolization, 141
Emergency Department (ED), 7
Emergency department thoracotomy (EDT), 241–246
Emergent tube thoracostomy, prophylactic antibiotics, 85, 86, 92–95
Endoluminal stenting, 80
Enteric feeding, 223, 224
Enteroatmospheric fistula, 74
Enterocutaneous fistula, 74, 75, 79, 80
Equity, Quality, and Inclusion in Trauma Surgery Practice Task Force (#EAST4ALL), 353
ER full meal deal, 9
Expeditionary Medical Group (EMDG), 383
Extracorporeal life support (ECLS), 251
Extracorporeal membrane oxygenation (ECMO)
all-cause ARDS, 255, 256
contraindication, 251, 256, 257
definition, 251
hemorrhage, thrombosis and anticoagulation management, 258–260
indications, 256, 257
modes and configurations, 255
operative procedures, 261
pulmonary trauma, 257, 258
randomized controlled trial, 263
recommendation, 262
respiratory failure, 260, 261
search strategy, 252–255
transport, 262
traumatic brain injury, 260, 261

F
Fasciotomy and Vascular Injury Outcomes (FaVIO) database, 383
Fecal diversion, 229
colostomy, 230–232
ileostomy, 229–231
Femoral access in this hemodynamically unstable patient population, 47
Femoral and iliac artery ligation, 381
Fistulas
anatomy, 75
antimotility and antisecretory agents, 75
cross-sectional imaging and fistulograms, 75
ECF development, 77
electrolyte imbalances with fluid shifts, 78
empiric antibiotics, 75
enteral access, 76
external loss of fluids, 75
intraoperative techniques, 79
local wound care, 78
lysis of adhesions, 79
maintenance phase, 78
management and operative planning, 75
medical clearance, 79
metabolic and infectious issues, 74
nutrition support for patients, 76
nutritional optimization, 78
in open abdomen, 77–79
operative intervention, 78, 80
operative repair, 79
pouching systems, 76
re-fistulization, 78, 79
skin breakdown, 76
skin hypersensitivity, 76
in trauma, 73
Focused assessment with sonography in trauma (FAST), 272, 273, 344
Forward Surgical Teams (FSTs), 381

G
Ganga Hospital Injury Severity Score, 395
Gelfoam, 145
Geography, 28
Geriatric Trauma Outcome Score, 40
Glasgow Coma Scale (GCS), 39
Ground EMS (GEMS), 25
Gunshot wounds (GSW), 49

H
Hannover Fracture Scale-97 (HFS-97), 395
Helicopter Emergency Medical Services (HEMS), 25, 26, 28–32
clinical risk, 31
cost of air ambulance services, 30
and effect on mortality, 27
in-hospital survival and discharge home, 28

Helicopter Emergency Medical Services (HEMS) (*cont.*)
limitations in study design, 25
patient selection, 26, 29
physician-adjudicated launching criteria, 29
physiologic criteria, 32
PICO table, 26
prehospital management, 30
recommendations on use, 28
remote scene and difficult terrain access, 28
residence-to-helicopter base distance, 26
substantial variability in methodology, 31
transport time model of improved mortality, 30
Hemodynamic stability, 135
Hemorrhage control in austere environments, 48, 49
Hemorrhage from traumatic injury, 35
Hemorrhagic shock, 35–41, 141
Hemostatic resuscitation, 4, 35
Hemothorax, 282
causes, 281
definition, 281
management, 283, 284
pigtail catheters, 284
recommendation, 285
retained hemothorax, 284
search strategy, 282
High velocity blunt trauma mechanism, 136
High-sensitivity cardiac troponin (hs-cTn) assays, 271
Hospital-associated (HA-IAI), 105, 106

I

IgM memory B-cells, 119
Immune function following splenic arterial embolization, 119
Immune function of the spleen after embolization, 118
Immunizations after splenic artery embolization following trauma, 120–121
Infectious complications after tube thoracostomy, 92, 93
Infectious Disease Society of America (IDSA), 106
Injury Severity Score (ISS), 26, 29, 134, 144
Intermittent occlusion REBOA (iREBOA), 53
Intervention Type and Intervention Strategy for Selected Violence Prevention Programs, 371, 373
Intra-abdominal hypertension (IAH), 183
Intra-abdominal pressure (IAP), 183
Intraabdominal sepsis, 74
Intracranial pressure (ICP), 181, 182
Intrapleural fibrinolytic therapy (IPFT)
American Association for the Surgery of Trauma (AAST), 289
authoritative practice guidelines, 292
clinical indications, 289
Eastern Association for the Surgery of Trauma, 292
observational studies, 288
PICO, 288
tPA, 288, 290, 292, 293
urokinase (UK), 289
VATS, 292
video-assisted thoracoscopy, 289
Intra thoracic pressure (ITP), 183

J

Joint Trauma System (JTS), 49

L

Large bowel injury, 99
Limb Salvage Index (LSI), 394
Lower Extremity Assessment Project (LEAP) group, 392
Low velocity blunt trauma, 134, 135

M

Magnetic resonance imaging (MRI), 163, 272
c-spine injury, 163
CT scan, 168, 169
flexion and extension x-rays, 163
guidelines, 164, 165
recommendations, 166–168
screening, 165, 166
search strategy, 164
timing and risk, 166
Major adverse cardiac events (MACE), 272
Management of penetrating injuries to the abdomen, 99
Mangled extremity, 386
age, 398
American College of Surgeons, Committee on Trauma, 392
amputation, 396
classification of, 394
clinical outcomes, 399
concomitant injury pattern, 397
debridement, 395

delayed (secondary) amputation, 398
Ganga Hospital Injury Severity Score, 395
Gustilo-Anderson classification, 393
HFS-97, 395
higher-energy mechanism, 396
ICD codes, 392
LEAP group, 392, 399
limb reconstruction, 398
limb salvage, 391
long-term functional recovery, 395
LSI, 394
MESI, 393
MESS, 393
nerve injuries, 397
NISSA, 394
open fractures, 393
PICO process, 392
PSI, 393
reconstruction and rehabilitation, 391
soft tissue defects, 398
treatment, 395
upper limb injuries, 399
vascular injuries, 396, 397
Mangled Extremity Severity Score (MESS), 393
Mangled Extremity Syndrome Index (MESI), 393
Massive transfusion (MT) protocols, 36
abnormal arterial blood gas, 38
activation, 39
decision-making process, 40
definition of, 36
in elderly population, 39, 40
futility, 36
markers of futility in the general trauma population, 37–39
metrics, 38
mortality rate of hemorrhagic shock, 35
multiple regression analysis, 38
in pediatric trauma patients, 40
prehospital and trauma systems of care, 36
on PUBMED, 37
resource limited environments, 40
trimodal distribution, 36
Meropenem, 111
Metallic coils, 145
Metronidazole, 111
Microbiological response, 107
Military Joint Trauma System, 9
Military, airway issues, 6
Mixed trauma center (MTC), 443, 444
Modified algorithms, 49
Monro-Kellie doctrine, 183
Moral distress, 350
Moxifloxacin (IV/PO), 111
Multicomparment syndrome (MCS), 181, 184, 185
Myocardial contusion, 272

N

National Trauma Data Base (NTDB), 443
Negative pressure wound therapy (NPWT), 61–68, 76
granulation tissue coverage, 63
hospital length of stay, 65–66
impact on wound healing, 63–65
infectious complications, 66–67
microdeformation, 61
patient-centered outcomes, 67
quality of life, disability, and pain, 67
traumatic extremity wounds, 61
treatment of traumatic superficial and deep soft tissue defects, 61
and wound healing recommendation, 64
Non-compressible torso hemorrhage (NCTH), 45, 48, 49, 52
Non-compressible truncal hemorrhage, 9
Non-selective arterial embolization, 140–149
Non-selective bilateral embolization of the entire internal iliac system, 146
Non-selective embolization, 140, 145–147

O

Octreotide, 75
Operation Enduring Freedom, 6
Operation Iraqi Freedom, 6
Organ donation
aggressive resuscitation, 343
brain-dead, heart-beating donors, 340
CPR, 343
cultural challenges, 339
family consent, 339
non-heart-beating donors, 340
presumed consent, 342
resuscitative thoracotomy (*see* Resuscitative thoracotomy (RT))
volunteer donation policy, 342
Ostomy
analysis, 228
blunt and penetrating injuries, 227
colostomy, 230–232
complex factors and decisions, 234–236
creation, 228
diverting/protective ostomies, 233
early closure *vs*. delayed closure, 232
Hartmann's procedure, 233, 234

Ostomy (*cont.*)
ileostomy, 229–231
limitation, 228
mortality and morbidity, 227
primary anastomosis, 234
risk factor, 228
safety and efficacy, 234
search strategy, 229
temporary stomas, 228
Over-triage, HEMS, 29

P
Packed red blood cells (PRBC), 39, 144
Pancreaticoduodenectomy, 223
Partial REBOA (pREBOA), 53
Partial thromboplastin time (PTT), 178
Pediatric trauma center (PTC), 442, 447
ALARA safety principles, 445
American College of Surgeons, 442
golden hour, 445
mortality rate, 443–445
outcomes measures, 443
pediatric experts, 445
single-center and state-based studies, 443
superior risk-adjusted mortality rates, 443
Pelvic angiography with embolization, 141
Pelvic fractures, 140, 142, 145–148
Pelvic haemorrhage from fractures after blunt trauma, 148
Pelvic re-bleeding, 148
Pelvic ring, 142
Penetrating abdominal trauma, 210–212, 214
clinical and hemodynamic findings, 433
cooperative multicenter prospective randomized control trials, 437–438
diagnostic laparoscopy, 438
diagnostic peritoneal lavage (DPL), 433
Embase database, 432
evisceration, 435
failure of conservative management, 434
immediate laparotomy, 433
initial operative management, 433
local wound exploration (LWE), 433
management guidelines, 432
MEDLINE database, 432
mortality rate, 431
National Trauma Data Bank (NTDB), 432
non-therapeutic laparotomy rate, 434
for pediatric penetrating abdominal trauma, 436, 437
peritonitis and hemodynamic stability, 434
physical examination, 431
PICO process, 432
selective non-operative management (NOM), 431
SIPA, 434
stable pediatric patient, 435, 436
Penetrating Abdominal Trauma Index (PATI), 100
Penetrating trauma, 128
Persistent hemodynamic instability, 140
PICO questions for the issue of airway first versus circulation first approach, 5
Pigtail catheters, 284
Poiseuille's law, 283
Popliteal artery injuries, 397
Portal venous scan, 143
Post-intubation cardiopulmonary arrest, 7
Post-intubation traumatic cardiopulmonary arrest, 8
Postoperative enterocutaneous fistula closure, 74
Post-traumatic retained hemothorax (PTRH)
complications, 287
intrapleural fibrinolytic therapy (*see* intrapleural fibrinolytic therapy (IPFT))
observational clinical studies, 288
treatment approaches, 287
Post-traumatic stress disorder (PTSD), 355
2015 Pragmatic Randomized Optimal Platelet and Plasma Ratios (PROPPR) trial, 36
Predictive Salvage Index (PSI), 393
Pre-hospital/ER/OR intubation, 7–8
Profound Hemorrhagic Shock Algorithm for RT/REBOA, 50
Prophylactic antibiotics for emergent tube thoracostomy, 85, 92–96
Psychological defense mechanism, 355
PUBMED, 5
Pyloric exclusion, 222

R
R Adams Cowley Shock Trauma Center (STC), 342
Radiation exposure, 147
Randomized controlled trials (RCTs), antibiotic regimens, 107
Rapid sequence intubation (RSI), 8, 9
REACT-2 trial, 128, 129
Recurrent infection and extra-abdominal infection, 112–113
Refractory intracranial hypertension (ICH)
abdominal decompression *vs*. standard medical therapy, 182

abdominal pressures, 186
decompressive laparotomy, 184
IAP, 183
ICP, 182
MCS, 181, 184–186
recommendations, 185
search strategy, 182
TBI, 181
RESCUicp Trial, 182
Resilience training, 351
American Psychological Association, 350
binary approach, 355
bounce back, 355
burnout, 350, 352, 356–358
compassion fatigue, 350
coping mechanisms, 355
evidence-based mechanisms, 354
GRADE approach, 353
guidelines and recommendations, 353
literal applications, 349
moral distress, 350
national sleep guidelines, 356
occupational stress, 357
PICO, 352
psychological defense mechanism, 355
PTSD, 354
racial trauma and race-based traumatic stress, 351, 352
search strategy, 352
self-awareness, 355
sleep deprivation, 356
societal-level trauma, 354
solutions/recommendations, 360–362
support systems, 357
TIC, 352, 355
trauma informed care, 354
trauma surgery, 357
wellness and self-care, 356
Resource limited environments, massive transfusion, 40
Respiratory failure, 260, 261
Resuscitation, 4, 140
Resuscitative endovascular occlusion of the aorta (REBOA)
comparative morbidity of undergoing a large chest wall incision, 52
complications and limitations, 52–53
civilian trauma care, 46
evolution in resuscitation paradigms, 46
indications and certification, 54
in-hospital management, 49–51
limitations, 53
procedural complexity, 47
RT use in the military setting, 47
Resuscitative thoracotomy (RT), 45, 46
age restriction, 342
clinical evidence
AORTA registry, 245
blunt injury, 244
cardiac motion, 246
contraindications, 245
COT, 243
overall survival rate, 244, 245
pediatric trauma patients, 246, 247
penetrating injuries, 242
PMGs, 243
stab wounds, 243
CPR, 247
culture and policy, 342
EDT, 241, 242, 244
family and patient sociodemographics, 342
FAST, 344
feasibility of, 342
history, 241
in situ perfusion, 342
occupational exposure, 345
PICO, 340
PUBMED search, 340
R Adams Cowley Shock Trauma Center (STC), 342
recommendations, 245, 247
search strategy, 242
survival rates, 340
Retained hemothorax (RH)
chest tube irrigation efficacy, 311
PICO, 310
prophylactic thoracic irrigation, 311, 312
recognition and management, 310
standard tube thoracostomy placement, 310
surgical intervention, 310
tube thoracostomy TT, 309, 312
VATS (*see* Video assisted thoracoscopic surgery)
Revised Injury Severity Classification (RISC), 132
Revised Trauma Score (RTS), 29
Rib fractures
ARDS, 303
cost effectiveness, 303
hospitalization stay, 302
indications and method, 297
in-hospital pneumonia, 303
intensive care stay, 302
mechanical ventilation, 299, 302, 305
mortality, 299
PICO table, 298
randomized controlled trials, 297–301
rib stabilization, 302

Rib fractures (*cont.*)
supportive ventilatory care, 297
surgery timing, 304
surgical fixation, 304, 305
surgical stabilization, 297, 305
tracheostomy, 303
treatment outcomes, 299

S
Same admission colostomy closure (SACC), 230
Secondary peritonitis, 111
Selective embolization, 146, 147
Selective non-operative management (SNOM), 214, 215
Shock index pediatric age-adjusted (SIPA), 434
Short-course antibiotics, 112, 113
Skyrocketing healthcare costs, 30–31
Social-ecological model (SEM), 370
Sound surgical decision-making, 79
Splenic arterial embolization (SAE), 119
Splenic embolization, vaccine prophylaxis, 117–119, 122
Stab wounds (SW), 242
STOP IT trial, 112, 113
Super selective embolization, 147, 148
Surgical Infection Society (SIS), 106
Surgical site infections (SSIs), 99

T
Temporary vascular shunts (TVS)
amputations, 383, 388
arterial repair, 382
blast injuries amputation rates, 384
civilian amputation rates, 385
in civilian setting, 384, 385
in civilian trauma, 382
for extremity vascular injuries, 382
FaVIO database, 383
iliac artery injuries, 386
mangled extremity, 386
maximum indwelling duration, 387
MEDLINE database, 382
and military amputation rates, 383–384
PICO, 382
placement, 387
restoration of blood flow, 388
with delayed graft repair, 386
Thoracic injury, 85
Thoracoabdominal trauma
ATLS program, 199
damage control maneuvers, 205
definition, 199
factors, 199
presentation and diagnosis, 201–203
recommendations, 203
search strategy, 200
Tigecycline, 111
Tile fracture, 142
Total parenteral nutrition (TPN), 76
Transesophageal echocardiography (TEE), 268, 271, 272
Transthoracic echocardiography (TTE), 271
Trauma and Injury Severity Score (TRISS), 132
Trauma and Organ Donation and Resuscitation, 340
Trauma evaluation and resuscitation process, 3
Trauma informed care (TIC), 352
Trauma Outcomes Group, 38
Trauma pan-scan, 136
Traumatic arrest algorithm For RT/REBOA for hemorrhagic shock, 50
Traumatic brain injury (TBI)
anticoagulation, 178
ARDS, 173
ECMO, 260, 261
ICH, 181
internal jugular veins, 178
PICO table, 174
recommendations, 174, 177, 178
search strategy, 174–177
VV ECMO, 173, 174, 178
Traumatic hemorrhage, whole blood, 13, 14
Traumatic injuries and hemorrhage requiring blood transfusion, 16
Trauma Quality Improvement Program (TQIP) database, 40
Tube thoracostomy (TT), 281–284, 309

U
UK-REBOA trial, 48
Under-triage, HEMS, 30
United Network for Organ Sharing (UNOS) registry, 333
Upper limb injuries, 399

V
Vaccine prophylaxis, splenic embolization, 117–119, 122
Vacuum assisted wound closure (VAC), 62, 63
Valveless vertebral venous system (VVS), 183
Vascular injuries, 396, 397

Venovenous extracorporeal membrane oxygenation (VV ECMO), 173
Vertebral artery injuries, 189
Video assisted thoracoscopic surgery (VATS), 287
  for blunt chest trauma, 317
  complications, 317
  cross-sectional chest imaging and evaluation, 321
  EAST practice management guidelines, 317
  hemothorax evacuation, 317
  infectious outcomes, 319
  intra-thoracic pathologies, 319
  multicenter AAST trial, 317
  multi-centered observational study, 319
  PICO, 316
  search strategy, 316
  and thoracoscopic drainage, 316
  treatment efficacy, 315
  treatment outcomes, 318
  ultra-early VATS, 317

W
War time treatment, 381
Western Trauma Association (WTA), 47, 140, 164
Whole-body CT scanning (WBCT)
  cost and length of stay, 132–134
  CT scans, 128
  in elderly patients, 134
  high speed motor vehicle collision, 136
  high-quality data on patients, 136
  mortality, 129
  PICO table for, 128
  prospective observational trials, 133
  randomized control trials, 129, 132, 137
  selective scanning group, 129
  systematic reviews and meta-analyses, 130–131
  time to diagnosis of injuries, 136
Whole blood transfusion, 13–19, 21
World Society of Emergency Surgery (WSES), 106

Y
Young-Burgess classifications, 142
Youth violence and injury prevention programs (YVIPPs)
  Bronfenbrenner's model, 370
  Butty Socioecological Model, 368
  case management, 374
  collaboration, 377
  common program evaluation techniques, 368
  community advocacy, 376
  community-initiated interventions, 367, 368, 371, 373, 375
  community-originated interventions, 368, 374
  community outreach workers (COWs), 368
  comprehensive community-originated interventions, 376
  definition, 367
  hospital-based interventions, 368
  mentoring, 374, 376
  one size fits all, 377
  PICO, 369
  practice components, 373, 374
  risk factors, 370
  search engines and databases, 368
  SEM, 370
  social disorganization, 372
  violence prevention practitioners, 377