Advances in Surgery 53 (2019) 221–233

ADVANCES IN SURGERY

What's New in Trauma Resuscitation?

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Keywords

• Trauma resuscitation • Damage control resuscitation • Permissive hypotension • Permissive hypoventilation • Whole blood

Key points

- Trauma resuscitation continues to evolve over time as the understanding of the physiology of hemorrhagic shock changes.
- Existing literature supports rapid transport of traumatically injured patients to a trauma center for definitive care.
- Trauma-induced coagulopathy should be addressed early in resuscitation to improve outcomes.
- Further studies are needed to define the optimal prehospital care.
- Trauma team training and video review improve patient care quality.

INTRODUCTION

Traumatic injury is the leading cause of death for individuals up to the age of 45 and the fourth leading cause of death among all ages in the United States [1]. Outside of preventive actions, little can be done for those who suffer immediate loss of life, but for the remainder of patients, the care provided in the very early stages after their injury can have profound impact on their eventual outcome. A better understanding of the physiology of hemorrhagic shock, trauma-induced coagulopathy, and goal-directed therapy has led to changes in the delivery of care early after injury. The objective of this article was to summarize approaches to the resuscitation of the critically injured patient that have recently come to the forefront. This article focuses on the role of the prehospital care

Disclosure Statement: The authors have no disclosures.

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https://doi.org/10.1016/j.yasu.2019.04.010

providers, damage control resuscitation (DCR) strategies, and the team approach to trauma care.

SIGNIFICANCE

Since 1978, the fundamental principles of Advanced Trauma Life Support (ATLS) have given trauma care providers a standardized framework for the rapid assessment and resuscitation of the injured patient. The structure is based on the concept that injuries kill patients in a reproducible pattern and allows for the prompt identification of those that are potentially fatal [2]. This paradigm was created largely from physician experience, not clinical study, as a comprehensive, reproducible way to provide trauma care that could be applied in any setting.

During the time that ATLS was being adopted, prehospital care was evolving. The development of sophisticated trauma systems and the implementation of prehospital emergency medical services (EMS) have contributed to an overall decrease in morbidity and mortality of traumatically injured patients; however, the addition of advanced life support (ALS) techniques in the 1980s has led to considerable discussion regarding the role of prehospital interventions, such as intravenous fluids (IVF) and endotracheal intubation (ETI). The use of IVF for hypotensive trauma patients was largely based on animal models in the 1960s that showed that end organ perfusion was restored with volume expansion and survival was increased [3,4]. In 1994, Bickell and colleagues [5,6] performed a landmark study in which patients with hypotensive penetrating trauma were assigned to receive immediate continuous IVF versus delayed fluid administration until operative intervention of their injuries. A significant survival advantage was seen in those patients with penetrating injuries not receiving IVFs. He and others theorized that IVF could accentuate blood loss, disrupt clot formation, and dilute coagulation factors [7].

In addition to circulatory support, prehospital providers are trained to prioritize management of the airway. In certain instances, the decision to perform ETI is clear, but at other times it requires significant expertise and clinical judgment. Traditionally, a Glasgow Coma Score (GCS) of 8 or less has been used to indicate a need for intubation, but this does not take into consideration assessment of potential injuries, hemodynamic status, or environmental factors.

There is mounting evidence against the use of prehospital ETI for patients with penetrating trauma who are in hemorrhagic shock. The positive pressure ventilation and changes in intrathoracic pressure with ETI lead to decreased venous return and cardiac output, and end organ perfusion. Drugs used in medication-assisted ETI potentiate these effects and may result in complete cardiovascular collapse in patients in hemorrhagic shock. At our institution, we compared ETI and mask ventilation in a rat and swine hemorrhagic shock model. There was no difference in the time to death [8,9]. When compared with swine receiving only supplemental oxygen via face mask (FM), the FM group had higher body temperatures, higher cardiac output, and lower lactate levels, but worse respiratory acidosis; however, the resultant hypercapnia did not result in worse survival. We concluded that “permissive hypoventilation” might allow for improved perfusion and oxygen delivery with decreased physiologic compromise [10].

In a clinical study, Stockinger and McSwain [11] showed there was no survival advantage to ETI in the penetrating population, whereas Rhee and colleagues [12] suggested that Bag-Valve-Mask is often adequate ventilatory support for the obtunded patient. Furthermore, ETI has a negative impact on survival in those patients requiring resuscitative thoracotomy [13], while not decreasing the rate of in-hospital complications [14]. EMS providers should have a clear airway algorithm that takes into account injury patterns, mechanisms, transport time to a trauma center, and physiologic consequences of ETI in order to reserve ETI situations where there is a benefit.

Although instituting the ATLS algorithm improved standardization and introduction of ALS changed practice, over time there has been a growing understanding of the physiologic burden of hemorrhagic shock. The development of the lethal triad of coagulopathy, acidosis, and hypothermia related to blood loss can be a precursor to mortality. The introduction of damage control surgery to control hemorrhage and contamination, minimize operative time, and allow for ongoing resuscitation to occur in the intensive care unit changed the way trauma surgeons managed those in profound shock [15]. Similarly, DCR aims to recognize coagulopathy early and address all elements of the lethal triad concurrently [16]. With this idea, the rigid adherence to the ATLS sequence of airway, breathing, circulation has come into question, with many advocating a circulation first method of trauma care resuscitation [17–19].

PRESENT RELEVANCE AND FUTURE AVENUES

Prehospital care

In 1996, Demetriades and colleagues [20] performed the first large-scale comparison of patients transported via paramedics versus private vehicle and showed that those patients with an Injury Severity Score greater than 15 transported by EMS had a mortality rate that was double that of the non-EMS patients. The investigators contended that the improved survival was likely due to decreased transport times and fewer therapeutic interventions being performed in the field. Since that time, there has been a continued attempt to define what components of ALS care should be provided that would be of benefit to the care of the trauma patient. Most of these studies are limited by study design, limited data availability, and reliance on bystander observations in the case of private and police transport. Even with these limitations, the data support foregoing procedural interventions prehospital and rapid transport to a trauma center where patients can receive definitive management of their injuries improves outcomes [21–25] (Table 1).

Damage control resuscitation and its adjuncts

Permissive hypotension

Permissive hypotension is the practice of keeping blood pressure low enough to avoid exsanguination, but still allow for end organ perfusion. In permissive

Table 1
Summary of studies comparing transport type

Author	Transport type	Study design	Outcome
Demetriades et al [20], 1996	Paramedic vs private	Retrospective	ISS >15 with EMS mortality 29% vs 14% in private transport
Liberman et al [22], 2003	ALS vs BLS	Retrospective	ALS mortality 29% vs BLS 18% ALS mortality 30% vs BLS mortality 26% in patients with survivable injuries
Seamon et al [13], 2007	EMS vs police/ private vehicle	Retrospective	Prehospital procedures have a negative effect on mortality in patients requiring resuscitative thoracotomy
Steill et al [23], 2008	ALS vs BLS	Before—after controlled trial	GCS <9 with decreased survival with ALS Overall survival not significantly different
Band et al [24,25], 2010 and 2011	EMS vs police	Retrospective	Increased survival in GSW/stab when brought via police
Seamon et al. [26], 2013	ALS vs BLS	Prospective observational	Prehospital interventions do not benefit rapidly transported penetrating trauma patients
Rappold et al [21], 2015	ALS vs BLS vs police	Retrospective	ISS <30 with increased odds of death with ALS ISS >30 no survival advantage with ALS
Evans et al [27], 2016	ALS	Retrospective	No prehospital procedures associated with survival benefit Airway insertion portends worse odds for survival

Abbreviations: ALS, advanced life support; BLS, basic life support; EMS, emergency medical services; GCS, glasgow coma score; ISS, injury severity score
Data from Refs [20,21,23–27].

hypotension, systolic blood pressure is targeted to 80 to 90 mm Hg to help avoid clot disruption and minimize the sequela of hemorrhagic shock. Dutton and colleagues [28] and Schreiber and colleagues [29] performed randomized controlled trials of patients in hemorrhagic shock comparing outcomes after fluid administration targeted to a goal systolic blood pressure. The investigators of both studies determined that hypotensive resuscitation was safe, but were unable to show an overall mortality difference; however Schreiber and colleagues [29] did show a trend toward improved 24-hour and in-hospital mortality in the hypotensive group. When applied in the operating theater, permissive hypotension may lessen postoperative coagulopathy and nonsurgical bleeding [30]. The combination of demonstrated safety of permissive hypotension and the increasing evidence to support minimizing crystalloid fluid administration led to a change in the ATLS content. The new recommendations advocate for permissive hypotension and limiting crystalloid to 1 to 2 L before consideration of blood products [2]. Careful consideration of this approach should be taken in patients with traumatic brain injury in which hypotension may result in secondary brain injury.

Hemostatic resuscitation

The coagulopathy of trauma represents a significant challenge in DCR with an incidence of more than 50% in the most critically ill patients [31]. The development of coagulopathy is the result of tissue injury and hypoperfusion that is perpetuated by hemodilution, acidosis, hypothermia, and inflammation [32]. As platelet and coagulation factors are consumed, pH drops and body temperature decreases, and the body's ability to form clot is impaired. Many of these changes occur very early after injury, necessitating early recognition and prevention or correction. Hemostatic resuscitation attempts to address these issues using a strategy of limited crystalloid and early transfusion of blood products with high fresh frozen plasma (FFP) to packed red blood cell (PRBC) ratios.

The use of massive transfusion protocols (MTPs) has allowed for more uniformity in achieving these ratios. The Pragmatic Randomized Optimal Platelet and Plasma Ratios trial randomized patients to a 1:1:1 versus a 1:1:2 platelet:plasma:PRBC transfusion strategies and attempted to define the ideal ratio. Although they were not able to show a 30-day all-cause mortality benefit, the 1:1:1 group did have more patients achieve hemostasis and fewer patients die from bleeding within the first 24 hours [33]. Most MTPs aim to deliver close to a 1:1 ratio of FFP:PRBC, as it confers a survival advantage to lower ratios and historical transfusion strategies [34,35]. The implementation of MTP practices have resulted in earlier blood administration, decreased cost, and lower total blood use over the course of a patient's hospital stay [36]. MTPs correlate with a decrease in the incidence of death from exsanguinating hemorrhage and an increase survival to discharge in the patients requiring the highest number of transfusions [37,38]. The rate-limiting step in supplying blood at these ratios is the need for FFP to be thawed before release from the blood bank. The process for thawing plasma takes approximately 20 to 30 minutes, which can lead to lag times to the start of the first plasma transfusion in comparison with the first PRBC. Several large studies, including the Prospective Observational Multicenter Major Trauma Transfusion study, have shown the advantages of early plasma administration [39]. Initiation of thawed plasma (TP) protocols, whereby TP is available in either the blood bank or the emergency department at all times, significantly decreases mortality, blood product utilization, and massive transfusion rates [40,41].

Platelet transfusion is also a crucial element in DCR; however, the exact timing and ratio of platelets to FFP and PRBC remains an area of debate. Higher platelet to PRBC and platelet to FFP ratios result in increased 24-hour and 30-day survival [42], but studies to date have examined only intraoperative platelet transfusion. The effect of immediate platelet administration is yet to be elucidated. Difficulties with storage, availability, risk of contamination, and immunologic sensitization poses a significant challenge to incorporation of platelets in the very early stages of resuscitation [43] (Box 1).

Whole blood transfusion

Although component therapy is commonplace, the use of whole blood (WB) has made a resurgence. WB provides higher platelet counts and increased coagulation factors while containing less preservative and anticoagulants, leading to greater hemostatic potential than 1:1:1 component therapy [44]. During the wars in Iraq and Afghanistan, warm fresh WB (WFWB) became a logistical necessity because of scarce supply and difficulty with transporting and maintaining blood products in the remote environment [45]; however, in retrospective studies from military practice, the use of WB has been associated with mixed effects on mortality and total transfusion needs [46,47]. In civilian practice, there has been resistance to use of WB due to misconceptions regarding safety of non-ABO group specific WB, loss of platelet presence with leukoreduction, and loss of platelet function in cold storage. The risk of significant hemolytic reactions with low-titer anti-A and anti-B group O WB is minimal and the recent production of platelet sparing leukoreduction filters will allow for platelet containing WB products to be available. In 2015, the Food and Drug Administration approved the storage of apheresis platelets at temperatures of 1 to 6° Celsius to be used in the resuscitation of actively bleeding patients [44].

Clinical application of WB in the civilian arena has shown promising results. In a randomized controlled pilot trial, Cotton and colleagues [48] compared modified WB and component therapy in patients predicted to require massive transfusion. When excluding patients with traumatic brain injury, the WB group received significantly less PRBC, FFP, platelets, and total transfusions. WB products have also been shown to improve platelet function and decrease the acute coagulopathy after trauma, while not impacting clinical outcomes [49–51]. The encouraging results of WB use in trauma centers and the prehospital care of military casualties has led to the development and implementation of prehospital WB transfusion protocols in 3 areas of Texas beginning in 2017.

Viscoelastic hemostatic assays

With approximately one-third of patients presenting to the hospital with coagulopathy, it is essential to be able to have early monitoring of coagulation.

Box 1: Key elements of damage control resuscitation

- Control of hemorrhage
- Permissive hypotension
- Hemostatic resuscitation
- Prevention/Correction of acidosis
- Normothermia
- Correction of hypocalcemia

Conventional plasma-based coagulation test, such as prothrombin time, activated partial thromboplastin time, and international normalized ratio serve mainly to measure clot initiation time and do not assess the interplay of platelets and coagulation factors in forming clot. Viscoelastic hemostatic assay (VHA), thrombelastography (TEG), or rotational thromboelastometry measure clot formation and dissolution in WB and can identify the etiology of coagulopathy (Fig. 1). On admission to a trauma center, TEG has been shown to be a more accurate predictor of need for blood product transfusion than conventional coagulation assays, and if reduced clot strength is present, there is associated increased 30-day mortality [52,53]. Also, VHAs provide clinically pertinent information in a short time frame, making it relevant for clinical decision-making regarding transfusion. Patients receiving TEG-guided MTP have better survival, less use of FFP and platelets, and better characterization of their unique coagulation profile [54]. Identification of factor depletion or fibrinolysis as the underlying cause of coagulopathy can steer resuscitation efforts and inform decisions regarding administration of antifibrinolytic agents.

VHA has benefits in resuscitation of the severely injured patient, but it has several obstacles to widespread adaption. Performance of the VHA test requires trained personnel and readily available equipment. Many hospitals house their equipment in a central laboratory and the times to results are influenced by limitations of laboratory resources. Point of care testing is appealing for trauma resuscitation, as it eliminates the need for involvement of a central laboratory, but those performing the test must be trained to ensure quality of results and the equipment requires frequent calibration and upkeep. As the technology of VHA evolves to become less labor intensive, it will be incorporated into more resuscitation algorithms due to its clinical advantages.

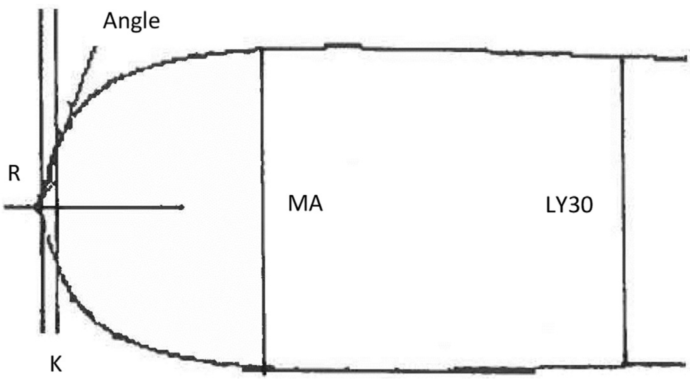

Fig. 1. Sample TEG tracing. K, clot amplification; LY30, % decrease of amplitude at 30 minutes; MA, maximum clot strength; R, clot initiation; α, speed of fibrin buildup and crosslinking.

Tourniquet placement

Hemorrhage control is a crucial component of DCR. Previously, tourniquet use for exsanguinating extremity injuries fell out of favor because of the concern for compounding the ischemic insult by restricting collateral circulation. The military conflicts in Iraq and Afghanistan saw many casualties from isolated limb injuries that were potentially preventable. This changed the military's stance on tourniquet use and availability in the field [55]. This has been extrapolated to the civilian trauma by EMS providers and through the Stop the Bleed campaign, which supplies citizens with tourniquets and education on their application.

Resuscitative endovascular balloon occlusion of the aorta

In recent years, the use of resuscitative endovascular balloon occlusion of the aorta (REBOA) has been gaining momentum as an endovascular approach to control noncompressible torso hemorrhage. White and colleagues [56,57] published a series of animal studies looking at the use of REBOA in a swine hemorrhagic shock model and showed that balloon aortic occlusion resulted in similar increases in central aortic pressure and carotid blood flow with less acidosis and less fluid and pressor requirements compared with open occlusion. Small clinical case series from various institutions showed that REBOA is a feasible option for control of noncompressible torso bleeding, but mortality rates are equivocal and safety concerns exist regarding access site complications [58–62]. Currently, the American Association for the Surgery of Trauma Aortic Occlusion for Resuscitation in Trauma and Acute Care Surgery study group is evaluating indications and outcomes for REBOA use. Early data from the registry suggested that there is no significant difference in mortality between open and endovascular occlusion of the aorta; however, this group and others have shown there may be a benefit in specific subsets of patients, including those with significant pelvic fractures [58,63].

The ultimate role of REBOA in the clinical setting remains in question. In the Joint Statement from the American College of Surgeons Committee on Trauma and the American College of Emergency Physicians regarding the clinical use of REBOA, it was recommended that practitioners undergo formal procedural training, have proficiency in ultrasound-guided and open access to the common femoral artery and participate in ongoing competency programs related to use of REBOA [64]. This statement received criticism in both the civilian and military community because it was overly restrictive and because of its lack of acknowledgment of the Joint Trauma System Clinical Practice Guideline for the use of REBOA published in 2017, which established clear indications for considering the use of REBOA in the combat setting, performing quality improvement, and system reporting [65,66].

The ultimate role of REBOA in the clinical setting remains in question. As the evidence continues to evolve regarding its use, practitioners will hopefully see clarification surrounding its indications, pitfalls, training, and outcomes.

TEAM TRAINING AND VIDEO REVIEW

A systematic and team-based approach to trauma bay resuscitation is a critical component of an injured patient's care. Medical errors most frequently occur as a result of ineffective leadership, poor communication, and lack of situational awareness [67,68]. Training of health care professionals in nontechnical skills, such as teamwork, stress management, decision-making, and communication, has long been recommended to improve patient care quality and patient safety. Following modeling approaches seen in the aviation industry and the military over many decades, trauma centers have begun to incorporate simulation-based team training into their performance improvement initiatives. Although still in its relative infancy, human patient simulator training has shown promising results in improving trauma bay efficiency, teamwork, and interpersonal and closed loop communication skills [69,70].

In concert with simulation training, the use of trauma video review (TVR) has become an invaluable tool for appraising trauma team performance. Hoyt and colleagues [71] first introduced this concept in the literature in 1988 and found that the use of TVR improved adherence to assigned responsibilities and a decrease in time to definitive care for the patients. Since that time, TVR has been used to identify and monitor system issues, to develop leadership skills, to ensure adherence to protocols, and more recently for procedural training [72].

FUTURE ADVANCES

The current available literature in trauma resuscitation has notable limitations from study design, selection bias, unmeasured confounders, and availability of resources, making widespread application of their results problematic. Future research efforts should be planned to minimize these issues to provide concrete evidence of best practices in early-phase trauma care.

There is a large volume of literature to support immediate transport of penetrating trauma victims to a trauma center for definitive care; however, EMS providers are still performing prehospital interventions that potentially delay transport and surgical intervention. At the same time, the early administration of blood components and/or WB decreases trauma-induced coagulopathy and many EMS systems are beginning prehospital transfusion protocols. These 2 statements seem to be contradictory and evoke many questions that are yet to be answered. When does the benefit of rapid transport no longer outweigh the benefit of prehospital blood product administration? In Philadelphia, most penetrating trauma victims are transported via police to the nearest trauma center for definitive care. Should other urban areas look to their other public service workers, such as police, to transport patients in order to get them to the hospital more quickly? A prospective randomized controlled trial designed to investigate the role of prehospital interventions is needed to definitively answer these questions.

SUMMARY

Trauma resuscitation continues to change over time. The role of prehospital care providers remains to be fully defined and the optimal resuscitation strategies are in evolution. The initial management of the trauma patient will continue to improve as the understanding of the physiology and coagulopathy of trauma is better refined.

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