Updates in Traumatic Cardiac Arrest

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KEYWORDS

- Cardiac arrest • Traumatic cardiac arrest • Pediatric trauma
- Cardiopulmonary resuscitation
- Resuscitative endovascular balloon occlusion of the aorta • Thoracotomy

KEY POINTS

- Traumatic cardiac arrest has persistently poor outcomes despite decades of research and refinement of treatment guidelines.
- Factors that predict survival in traumatic arrest include penetrating injury, short length of prehospital cardiopulmonary resuscitation, signs of life with emergency medical services or on arrival, cardiac motion on ultrasound, and pediatric patients.
- Emergency department thoracotomy can be performed in select situations that include pericardial tamponade, tension pneumothorax, and for external aortic cross-clamping to improve proximal tissue perfusion.
- Open chest compressions or cardiac massage may not be superior to closed chest compressions for traumatic arrest.
- Pediatric traumatic arrest patients remain poorly studied and represent a distinct clinical challenge.

INTRODUCTION

Trauma is among the leading causes of mortality and morbidity in industrialized nations.[1] Cardiac arrest caused by trauma historically carries a low likelihood of survival, with a high rate of permanent neurologic disability in survivors.[2,3] Approximately one-third of patients who sustain a traumatic cardiac arrest (TCA) die before arrival to a hospital.[4] Early studies suggested that patients with a TCA who had more than a few minutes of cardiopulmonary resuscitation (CPR) rarely survived.[5–7] As a result, some clinicians have advocated no resuscitation in most cases of TCA.[5–7] More recent studies have consistently reported that survival for TCA can be as high as 7%.[8–10] Pickens and colleagues reported that prehospital assessment of TCA was not reliable

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and recommended that all patients with TCA should be transported to the emergency department (ED) for further assessment and intervention. This and additional studies have demonstrated survival in patients despite receiving treatment and CPR outside of the time window currently recommended in guidelines for TCA.[9,10] Furthermore, survival from TCA may be higher with select etiologies that are rapidly reversible, including tension pneumothorax and cardiac tamponade.[11] Unfortunately, there has been relatively little improvement in patients outcomes despite evidence that neurologic outcomes may be higher than previously thought.[1,12] TCA is a complex disease and presents unique challenges to the ED physician for evaluation and treatment. This article focuses on a review of criteria for termination of resuscitation, important etiologies of TCA, and important components of the ED resuscitation of patients with TCA.

WITHHOLDING AND TERMINATION OF RESUSCITATION

TCA is a distinct disease process from patients who present to the ED with out-of-hospital cardiac arrest (OHCA) from medical causes. Predictors of survival following TCA include the mechanism of TCA, location of injury, and signs of life (SOLs) on arrival.[9] Although it is important to recognize that TCA can be a survivable disease, it is equally important to identify predictors of mortality when resuscitative efforts should be discontinued, or even withheld. Various guidelines exist for withholding or terminating resuscitation in TCA.[13–15]

In 2003, The National Association of EMS Physicians and the American College of Surgeons Committee on Trauma (NAEMSP/ASCOT) consensus guidelines stated "termination of resuscitation (TOR) may be considered when there are no SOL and there is no return of spontaneous circulation despite appropriate field EMS treatment that includes minimally interrupted cardiopulmonary resuscitation (CPR)."[14] Similarly, The Eastern Association for the Surgery of Trauma recommends thoracotomy for penetrating injury to thorax, but favors using SOLs as a measure of futility in resuscitative efforts.[16] The Western Trauma Association recommends time-based criteria based on the mechanism of injury (blunt trauma with >10 minutes of prehospital CPR and penetrating trauma with >15 minutes of prehospital CPR) that cessation of resuscitation and withholding ED thoracotomy should be considered.[15]

In 2012, NAEMSP/ASCOT updated their recommendations and marked a difference between criteria for withholding resuscitation and termination of resuscitation (**Boxes 1** and **2**). They concluded "In the setting of cardiopulmonary arrest secondary to trauma from both blunt and penetrating mechanisms, an evidence guided protocol for withholding resuscitation includes clear evidence that the patient is dead, and a protocol for TOR should include the following elements: no evidence of SOL including no pulse, no respirations, no blood pressure; and no ROSC after initiation of resuscitation by the EMS providers, which should include minimally interrupted chest compressions."[13]

ETIOLOGY OF TRAUMATIC CARDIAC ARREST

The etiology of TCA is due to many causes, but can be categorized largely due to penetrating or blunt injury.[10] TCA patients can be further categorized according to location of injury (**Boxes 3**and **4**) with several injuries that are potentially life-saving, correctable causes of TCA, amenable to immediate treatment by the ED physician.

Although subject to large regional variation, especially in North America where penetrating injury is much more common than in other countries, hemorrhage remains a leading cause of traumatic death.[4] The mechanism and location of hemorrhage are both important predictors of outcome following TCA. The literature has shown that

Box 1
The National Association of EMS Physicians and the American College of Surgeons Committee on Trauma 2012 position on withholding resuscitation in traumatic cardiopulmonary arrest

- It is appropriate to withhold resuscitative efforts for certain trauma patients for whom death is the predictable outcome.
- Resuscitative efforts should be withheld for trauma patients with injuries that are obviously incompatible with life, such as decapitation or hemicorporectomy.
- Resuscitative efforts should be withheld for patients of either blunt or penetrating trauma when there is evidence of prolonged cardiac arrest, including rigor mortis or dependent lividity.
- Resuscitative efforts may be withheld for a blunt trauma patient who, on the arrival of EMS personnel, is found to be apneic, pulseless, and without organized electrocardiographic activity.
- Resuscitative efforts may be withheld for a penetrating trauma patient who, on arrival of EMS personnel, is found to be pulseless and apneic and there are no other SOLs, including spontaneous movement, electrocardiographic activity, and papillary response.
- When the mechanism of injury does not correlate with the clinical condition, suggesting a nontraumatic cause of cardiac arrest, standard resuscitative measures should be followed.

From Millin MG, Galvagno SM, Khandker SR, et al. Withholding and termination of resuscitation of adult cardiopulmonary arrest secondary to trauma: resource document to the joint NAEMSP-ACSCOT position statements. J Trauma Acute Care Surg 2013;75:459-67.

penetrating trauma is associated with better outcome than blunt mechanisms, but the location of the injury greatly affects survival.[16] In 2015, Seamon and colleagues published an evidence-based approach to TCA following a systematic review of the literature. In their analysis, the authors report that patients who sustained a penetrating injury had an overall survival of 10.6%, with approximately 90% of survivors neurologically intact. However, only 15.8% of stab wounds survived, and just 7.2% of gunshot wounds survived. This contrasts sharply with blunt injuries, where only 2.3% of patients survived. Of these patients with blunt injuries, only 59.4% remained neurologically intact.

Tension pneumothorax (tPTX) accounts for approximately 6% to 13% of cases of TCA[8,17] and must be quickly evaluated and treated. Tube thoracostomy can be lifesaving, as tPTX is a potentially correctable cause of TCA. A robust urban emergency medical services (EMS) system in Berlin identified that approximately half of TCAs required a chest tube (one-third for tPTX), but only approximately 13% received a chest tube prior to hospital arrival.[17] Huber-Wagner and colleagues[8] found that early, prehospital thoracostomy was associated with increased survival. Identifying and releasing tension pneumothorax as soon as possible should be among the highest priorities in TCA.

Pericardial tamponade is a potentially reversible cause of TCA. Rapid identification and treatment with thoracotomy, or needle decompression if thoracotomy is unavailable, is important for patient survival and is a priority in treatment of TCA. Davies and Lockey[18] of the London Air Ambulance found that by utilizing early thoracotomy by prehospital physicians, the etiology of all survivors (13) of 71 patients in TCA was pericardial tamponade. Eleven of these patients were discharged with good neurologic outcome. The rapid identification and evacuation of pericardial tamponade should be a high priority for emergency physicians.

Box 2
The National Association of EMS Physicians and the American College of Surgeons Committee on Trauma 2012 position on termination of resuscitation of traumatic cardiopulmonary arrest

- A principle focus of EMS treatment of trauma patients is efficient evacuation to definitive care, where major blood loss can be corrected. Resuscitative efforts should not prolong on-scene time.
- EMS systems should have protocols that allow EMS providers to terminate resuscitative efforts for certain adult patients in traumatic cardiopulmonary arrest.
- Termination of resuscitation (TOR) may be considered when there are no SOLs, and there is no ROSC despite appropriate field EMS treatment that includes minimally interrupted CPR.
- Protocols should require a specific interval of CPR that accompanies other resuscitative interventions. Past guidance has indicated that up to 15 minutes of CPR should be provided before resuscitative efforts are terminated, but the science in this regard remains unclear.
- TOR protocols should be accompanied by standard procedures to ensure appropriate management of the deceased patient in the field and adequate support services for the patient's family.
- Implementation of TOR protocols mandates active physician oversight.
- TOR protocols should include any locally specific clinical, environmental, or population-based situations for which the protocol is not applicable. TOR may be impractical after transport has been initiated.
- Further research is appropriate to determine the optimal duration of CPR before terminating resuscitative efforts.

From Millin MG, Galvagno SM, Khandker SR, et al. Withholding and termination of resuscitation of adult cardiopulmonary arrest secondary to trauma: resource document to the joint NAEMSP-ACSCOT position statements. J Trauma Acute Care Surg 2013;75:459-67.

KEY COMPONENTS OF EMERGENCY MEDICAL MANAGEMENT OF TRAUMATIC CARDIAC ARREST

Ultrasound

The use of ultrasound in the primary survey of trauma has been a mainstay for decades.[19,20] It continues to be a valuable adjunct for the initial assessment of a trauma patient, both for the identification of reversible causes of arrest and the assessment of cardiac function when considering whether to withhold or terminate resuscitation efforts.[21] Ultrasound examination of the heart in the setting of cardiac arrest is part of the focused abdominal sonography for trauma (FAST) examination, specifically to identify

Box 3
Injury patterns in traumatic cardiac arrest

Polytrauma

Exsanguination

Isolated traumatic brain injury

Thoracic trauma

Abdominal trauma

Other causes

Box 4
Correctable causes of traumatic cardiac arrest and treatments

Injury	Treatment
Pericardial tamponade	Thoracotomy/needle pericardiocentesis
Tension pneumothorax	Thoracostomy
Thoracic hemorrhage	Thoracotomy
Abdominal hemorrhage	Thoracotomy/REBOA
Extremity hemorrhage	Tourniquet application
Hypoxia	Definitive airway management

hemopericardium leading to cardiac tamponade, which accounts for 10% of TCA cases.[17]

Cardiac ultrasound can also help predict survival in patients with TCA. In a single-center study of 162 patients with TCA who received cardiac ultrasound and electrocardiogram (EKG) tracing found a 4.3% survival to hospital admission.[22] "Survival was higher for those with cardiac motion on ultrasound than for those without cardiac." Ultrasound cardiac motion predicted survival to hospital admission with 86% sensitivity, 91% specificity, 30% positive predictive value, and 99% negative predictive value.[22] Sensitivity was 100% for penetrating trauma and 75% for blunt trauma. The authors concluded that "cardiac ultrasound had a negative predictive value approaching 100% for survival to hospital admission. For patients with prolonged prehospital cardiopulmonary resuscitation, ultrasound evaluation of cardiac motion in pulseless patients with trauma may be a rapid way to help determine which patients have no chance of survival in the setting of lethal injuries, so that futile resuscitations can be stopped."[22]

As discussed previously, the rapid assessment for pneumothorax in TCA is a high priority. The eFAST examination (**Box 5**) has become standard practice in trauma, with a higher sensitivity than chest radiograph for identifying pneumothorax. The authors recommend that the eFAST examination start with the subxiphoid or parasternal views, quickly followed by intercostal views to identify tPTX, which must be quickly evaluated and treated. Although needle decompression is classically the first-line treatment for tPTX, problems with catheter depth[23] and insertion[24] limit its effectiveness and should always be followed by finger or tube thoracostomy.

Emergency Department Thoracotomy

A patient with TCA who arrives to the ED should immediately be assessed for SOLs, as well as a determination of the length of CPR, as these data points inform the decision whether to proceed with an ED thoracotomy (EDT). Early studies on EDT suggested that only 4% of patients with TCA who received an EDT survived neurologically intact. Importantly, survival was found to be higher for patients with a stab wound to the thorax with SOLs (23%) and 38% among moribund patients who showed some SOLs.[25–27] Guidelines have been developed to guide clinicians on the critical decision to perform an EDT.

Importantly, current guidelines differ slightly by organization on whether EDT may be beneficial (**Boxes 6** and **7**) The Eastern Association for the Surgery of Trauma strongly recommends that EDT be performed in any patient with SOLs after penetrating thoracic injury, but make weaker conditional recommendations for patients with SOLs after penetrating extrathoracic and blunt injuries, as well as those without SOLs after penetrating thoracic and extrathoracic injuries.[16] The Western Association

Box 5
Components of an extended focused abdominal sonography for trauma examination

Subcostal

Inferior vena cava

Right upper quadrant

Left upper quadrant

Pelvis
- Sagittal view
- Transverse view

Intercostal views (bilateral)

for the Surgery of Trauma currently recommends EDT for patients undergoing less than 10 minutes of prehospital CPR after blunt injury, less than 15 minutes of prehospital CPR following penetrating injury to the thorax, less than 5 minutes of prehospital CPR in patients following penetrating injury to the neck or extremity, and patients in profound refractory shock. The Eastern Guidelines also recommend against EDT in those without SOLs following blunt injury.[28] These guidelines have remained relatively constant, with most experts agreeing that EDT should be performed in those with SOLs, especially following penetrating injury, during prehospital transport or on arrival to the hospital.

Closed Chest Compressions Versus Open Cardiac Compression

During the initial phases of resuscitation following TCA, closed chest compressions are the most expedient means to provide some degree of circulation to the body and perfuse the myocardium and brain. However, EDT allows the clinician the option to perform open chest cardiac massage (OCCM). OCCM is hand-assisted cardiac

Box 6
Eastern Association for the surgery of trauma guidelines for resuscitative thoracotomy

Strong Recommendation:
- Pulseless patient presenting to ED with SOLs after penetrating thoracic injury

Conditional Recommendations:
- Pulseless patient presenting to ED without SOLs after penetrating thoracic injury (consider time without SOL in decision making)
- Pulseless patient presenting to ED with SOL after penetrating nonthoracic injury (consider location of injury in decision making)
- Pulseless patient presenting to ED without SOLs after penetrating nonthoracic injury (few patients may benefit, low quality evidence, and excludes isolated intracranial injury)
- Pulseless patient presenting to ED with SOLs after blunt injury (some patients may not wish to undergo EDT considering concomitant severe traumatic brain injury)

Recommendation Against:
- Pulseless patient presenting to ED without SOLs after blunt injury (most patients would not wish to undergo EDT considering concomitant severe traumatic brain injury and dismal outcomes)

From Seamon MJ, Haut ER, Van Arendonk K, et al. An evidence-based approach to patient selection for emergency department thoracotomy: A practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg 2015;79:159-73.

Box 7
Western Trauma Association guidelines for resuscitative thoracotomy

Penetrating injury with CPR less than 15 minutes

Profound refractory shock (CPR with SOLs or systolic blood pressure <60 mm Hg)

Blunt injury with CPR <10 minutes

Data from Burlew CC, Moore EE, Moore FA, et al. Western Trauma Association critical decisions in trauma: resuscitative thoracotomy. J Trauma Acute Care Surg 2012;73:1359-63.

compression and is thought to augment or stimulate cardiac compression, improve filling of the heart, and improve perfusion to distal tissues. Some animal data suggest OCCM may be superior to closed chest compression (CCC) following nontraumatic cardiac arrest.[29] However, recent clinical data in TCA patients showed no difference in patient-oriented outcomes or end-tidal CO_2 ($EtCO_2$) in those who received CCC compared with those who received OCCM.[30] Although $EtCO_2$ has been shown to predict survival in patients with OHCA, it has been studied relatively little in the trauma population.[31,32] A recent study found that combining CCC with resuscitative endovascular balloon occlusion of the aorta (REBOA) in the setting of TCA resulted in "higher EtCO2 and cardiac compression fraction before and after aortic occlusion (AO) compared with patients who receive OCCM."[33] These data suggest that cardiac compressions following TCA utilizing endovascular adjuncts may benefit from more aggressive study.

Resuscitative Balloon Occlusion of the Aorta

The terms EDT and resuscitative thoracotomy (RT) are often used interchangeably. This can lead to confusion when discussing the use of REBOA in TCA. These are distinct procedures with similar, but not identical, indications. EDT is the term used for a thoracotomy performed for the reasons previously described. RT is a thoracotomy performed for the purpose of external cross-clamping of the aorta. Regardless of the method, the use of aortic cross-clamping in the setting of TCA is for the temporization of distal hemorrhage, supplementing cerebral and coronary perfusion by reduction of the vascular bed that requires perfusion by CPR or native cardiac output.

Recent small studies have suggested a benefit in the use of REBOA in TCA. One study found that mean cardiac compression fraction was significantly improved in TCA patients who received REBOA compared with patients who underwent RT. REBOA was also associated with shorter pauses in cardiac compression.[34] However, this study was not powered for patient-oriented outcomes. A follow-up study found that $EtCO_2$ was significantly improved among a similar population of patients who received REBOA.[33] This suggests that although chest compressions in a hypovolemic patient may be of limited benefit, CCC with or without aortic occlusion may carry some patient benefit versus OCCM.

In 2013, the American Association for the Surgery of Trauma (AAST) created the Aortic Occlusion in Resuscitation for Trauma and Acute Care Surgery (AORTA) multi-institutional registry to more rigorously study REBOA and RT. A recent interim analysis of the database has shown an improvement in survival beyond the ED and improved survival to discharge in patients who receive REBOA compared with RT. Eighty-five percent of those discharged had a Glasgow Coma Scale score of 15. Although the survival benefit in those who did not require CPR before aortic occlusion

was more pronounced, there was no survival benefit in those who arrived after prehospital arrest or in arrest. Patients who did not require CPR but presented with a systolic blood pressure less than 90 mm Hg had a significantly higher survival beyond the ED and to discharge with REBOA. The authors concluded "overall, REBOA can confer a survival benefit over RT, particularly in patients not requiring CPR. Considerable additional study is required to definitively recommend REBOA for specific subsets of injured patients." These preliminary data suggest a potential benefit of REBOA in the setting of TCA, but outside of a few high-volume centers, the data do not support widespread adoption of REBOA for this indication. It remains an active area of discussion and investigation at the time of publication of this article.[35]

PEDIATRIC PATIENTS

Pediatric TCA is a difficult issue for the emergency physician. This is further complicated by the lack of clear guidelines for this population. Zwingmann and colleagues[1] showed that children with TCA have a higher survival rate compared with adults, but suffered from worse neurologic outcomes. In this systematic review, it was unclear why blunt injury predicted better outcomes for pediatric patients with TCA, or why children suffer worse neurologic outcomes. Some have suggested that the etiology of TCA in children is respiratory compromise rather than exsanguination, and this may represent different pathology from adult patients.[36] There is no clear consensus on the resuscitation of pediatric populations in TCA. Most guidelines and recommendations are derived from data from primarily adult populations,[13,16,28] limiting their use in the pediatric TCA patient.

NOVEL ADVANCES

Extracorporeal resuscitation is an active area of research in TCA. Selective aortic arch perfusion (SAAP) has been shown to salvage a TCA swine model in 90% of animals. This technique has been studied for decades and is close to active clinical trials, but remains an investigative technique.[37] Extracorporeal preservation and resuscitation is currently being evaluated in clinical trials and has shown a survival benefit in dogs compared with a standard treatment model of TCA. However, this technique requires substantial resources to implement and will likely be outside the capabilities of most centers.[38] Extracorporeal life support is becoming more frequent in the setting of trauma, but is primarily using venovenous support for complications following trauma, including TCA. Use of ECLS as a primary adjunct for TCA remains exceedingly rare.[39] Extracorporeal membrane oxygenation (ECMO) is discussed in a separate article, "ECMO in the Emergency Department," in this issue.

SUMMARY

The evaluation and treatment of traumatic cardiac arrest remains a challenge to the emergency medicine provider. Guidelines have establish criteria for the patients who can benefit from treatment and resuscitation versus those who will likely not survive. Patient factors that predict survival are penetrating injury, SOLs with EMS or on arrival to the Emergency Department, short length of prehospital CPR, cardiac motion on ultrasound, pediatric patients, and those with reversible causes including pericardial tamponade and tension pneumothorax. Newer technologies such as REBOA, SAAP, and ECMO may improve outcomes, but remain primarily investigational.

DISCLOSURE

The authors have nothing to disclose.

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