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Trauma is the leading cause of death in patients between the ages of 1 and 44 years and is the fifth leading cause of overall deaths in the United States. The annual cost to care for trauma is estimated at between $260 and $440 billion. Each year, more than 150,000 patients die from traumatic injuries. It is estimated that between one-third[1] and one-half[2] of these deaths occur in the out-of-hospital environment and that up to 80% of these deaths occur within the first few hours of injury.[3] This suggests that many emergency medical technicians, emergency physicians, and trauma surgeons will face the challenge of traumatic cardiopulmonary arrest following traumatic injury as a part of their clinical practice. This article reviews the incidence, cause, and factors that impact survival following traumatic cardiopulmonary arrest.

— *The Editor*

Traumatic Cardiopulmonary Arrest

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Introduction

The decision to resuscitate a patient with traumatic cardiopulmonary arrest is not as simple as it may first appear. The course of action is only clear when the patient demonstrates signs of prolonged loss of vital functions (rigor mortis, dependent lividity) or an obvious unsurvivable injury (decapitation, hemicorporectomy). Many of these patients are young and in their most productive years of life; this creates an argument for aggressive management. This not only charges our decisions with an emotional element, but also implies that even limited success in the number of lives saved may reap large benefits in terms of potential economic benefit.

On the other hand, survival from traumatic cardiopulmonary arrest is unusual,[4-7] and the costs of futile resuscitation efforts can be significant. In addition, the healthcare provider must be cognizant of other concerns such as risk of exposure to blood and body fluids, consumption of valuable resources such as blood products, and risk of injury to pre-hospital providers during rapid transport.

The purpose of this article is to review the incidence and caus-

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es of traumatic cardiopulmonary arrest, identify factors that impact the outcome of these patients, and suggest a rationale approach to the management of traumatic cardiopulmonary arrest both in and out of the hospital environment.

Incidence of Trauma Arrest

The exact incidence of traumatic cardiopulmonary arrest is difficult to determine. There are an estimated 60 million people injured annually in the United States; approximately 5-10% of these patients are injured seriously. This equates to 3-6 million patients with serious injury yearly. This number can be validated by a derivation that suggests one in six of the 29.5 million patients admitted to the hospital for trauma (4.9 million hospitalizations) will have a serious injury.[8] If we assume that 80% of the 150,000 trauma deaths occur in either the out-of-hospital setting or during early resuscitation,[1-3] we can estimate that 2-4 patients out of 100 with significant trauma will suffer a traumatic cardiopulmonary arrest.

This derived estimate seems to track well with two large studies. Battistella and coworkers[9] described 604 traumatic cardiopulmonary arrests among 16,724 patients admitted to their Level I trauma center. This suggests 3.6 trauma arrests for every 100 admissions. Similarly, Stockinger and McSwain[10] found 588 traumatic cardiopulmonary arrests among 16,651 Level I trauma admissions or 3.5 trauma arrests per 100 admissions.

It is of interest that Falcone and colleagues[11] found 320 traumatic cardiopulmonary arrests among 12,518 air medical transports, or 2.6 trauma arrests per 100 transports. Presumably, many of the transported patients were not exclusively trauma patients. Margolin et al[12] found only 67 traumatic cardiopulmonary arrests among 14,905 transports. This represents a significantly lower incidence of 4.5 trauma arrests per 1000 transports and also may reflect a difference in referral patterns for air transport in their region.

Gathering more specific estimates in the scientific literature is difficult for several reasons. First, the definition of traumatic cardiopulmonary arrest varies among studies with regard to the inclusion of non-trauma diagnosis such as asphyxia, drowning, hanging, electrocution, and major burns. Many other studies include only those patients taken to trauma centers. Thus, they may underestimate the true incidence of traumatic cardiopulmonary arrest by excluding patients with early out-of-hospital death who may be pronounced in the field or transported to non-trauma hospitals. Other studies fail to identify the total number of patients admitted to the study facility or catchment area,[7,13,14] thus making any population or admission-based estimates difficult. Finally, many other authors tend to focus on segmented populations or specific mechanisms of injury,[15] which makes a true determination of incidence impossible.

Epidemiology of Trauma Arrest

It is important to understand the exact causes of early trauma deaths so that one can implement treatment protocols that address the most common causes of traumatic cardiopulmonary arrest. Baker and coworkers[16] were the first to describe the pattern of early trauma deaths. Blunt injuries caused 53% of deaths, and penetrating trauma caused an additional 40%. More than one-half of the patients (53%) died prior to arrival to the hospital, and 29% died in the first 48 hours. Sauaia et al[1] conducted a similar study in Denver. They found that 49% of deaths were due to penetrating trauma and 48% were due to blunt injury. In their study, 34% of deaths occurred before reaching the hospital and 53% died within the first 48 hours of admission. Patients with penetrating injury who reached the hospital tended to die early (first 48 hours), whereas those with blunt trauma typically suffered late deaths. Almost half (52%) of prehospital deaths were due to central nervous system (CNS) injury, and an additional 36% were due to exsanguinations or a combination of both injury patterns. In patients who died in the first 48 hours of admission, exsanguination was the major cause of death. Trunkey[2] noted that most of the out-of-hospital deaths were caused by CNS (brain and spinal cord injury) and major vascular trauma whereas early deaths were due primarily to exsanguination. These findings were recently validated in a rural setting[17] in which 42% of deaths were related to CNS injury, 20% were due to exsanguinations, and 8% were due to airway compromise.

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Correction

In the May/June 2007 issue of *Trauma Reports*, a sentence was noted incorrectly on page 3. It should have read: "Given the aging population of the United States, the incidence of hip fracture is estimated to exceed more than 500,000 cases by the year 2040."

Table 1. Leading Causes of Trauma Deaths

PREHOSPITAL	EARLY HOSPITAL
Major head injury	Hemoperitoneum
Spinal cord injury	Massive hemothorax
Traumatic aortic rupture	Retroperitoneal hemorrhage from major pelvic fractures
Major vascular injury	
Cardiac rupture	
Airway compromise	

The major prehospital and early hospital causes of death are listed in Table 1.

Factors Affecting Survival

Overall, survival from traumatic cardiopulmonary arrest is low. The survival in those studies focusing on prehospital traumatic cardiopulmonary arrest varies from 0-2.9%. *(See Table 2.)* Although much of this information is derived from studies on emergency thoracotomy, several authors have examined overall survival for those patients in which resuscitation and transport is provided. Two additional points need to be made about studies of traumatic cardiopulmonary arrest. First, there is no standardized definition or terminology that exists for this field that mirrors the the Utstein criteria used in studies involving primary cardiac arrest.[18] At a minimum, a gold standard for reporting results should be the number or percent of neurologically intact survivors. Additionally, it must be remembered that the overall survival rate for primary cardiac arrest, when measured in terms of neurologically intact survivors, is not significantly better than traumatic cardiac arrest, particularly in urban environments.[19,20]

Shimazu and coworkers[4] examined survival among 267 victims of traumatic cardiopulmonary arrest (including 217 blunt injuries and 55 penetrating injuries). There were 7 (2.6%) survivors; 4 (1.5%) were neurologically intact. Stratton et al[21] examined 1051 victims of traumatic cardiopulmonary arrest, including 497 penetrating injuries and 382 blunt trauma victims. One hundred sixteen patients were excluded for various reasons, including loss of pulse in the field. The survival rate was 0.8% for penetrating injury and 1.6% for blunt injury. Battistella and colleagues[9] found an overall survival rate of 2.6%, with nearly one-half of the survivors having neurologic sequelae. Other studies by Fulton et al[22] (2.6%) and Pasquale et al[14] (2.9%) confirm these results.

Recent studies, however, have demonstrated more promising results. Willis and coworkers[23] reported a survival rate of 4.5% among trauma arrests transported to the hospital over a four-year period. Their methodology did not include victims pronounced on-scene and also included other non-traumatic diagnoses such as electrocution. Cera and coworkers[7] noted 15 surviving patients among 195 patients (7.7%) arriving at their trauma center with CPR in progress, including 34 patients in which no resuscitation was attempted. Lockey et al[24] found a survival of 7.5% among 909 trauma arrests transported by air medical transport. This included a significant number of patients who were pronounced dead in the field. Finally, Pickens et al[13] also found an overall survival rate of 7.7% among 184 patients transported to a Level I trauma center with CPR in progress. Overall, 3590 patients with traumatic cardiopulmonary arrest were reported in these studies, with 180 (5.1%) survivors.

Several authors have evaluated more specific criteria that can be used to identify those victims of traumatic cardiopulmonary arrest, criteria that can be used to predict survival or reduce futile resuscitative efforts. These are described below.

Initial Cardiac Rhythm

At least five studies have addressed the impact of underlying cardiac rhythm on survival. Esposito and colleagues[25] were able to document an underlying rhythm in 102 of their study population. There were two survivors in this group: one with an underlying ventricular dysrhythmia and one with sinus-based PEA (pulseless electrical activity). No patient with asystole survived. Fulton et al[22] found that patients with an underlying ventricular dysrhythmia or PEA had a better outcome than those with asystole or an idioventricular rhythm. In fact, no asystolic patients survived. Interestingly, however, no patient who was defibrillated upon arrival to the trauma center survived. This contrasts with a study by Aprahamian et al[26] in which only patients who required defibrillation in the emergency department survived. In their series of 604 trauma arrests, Battistella et al[9] found no survivors among

Table 2. Survival from Traumatic Cardiopulmonary Arrest

AUTHOR	MECHANISM	NO. PATIENTS	NO. SURVIVAL	COMMENT
Shimazu et al[4]	Blunt, penetrating	267	7 (2.6%)	Only included those patients transported to hospital; only 4 neurologically intact
Stratton et al[21]	Blunt, penetrating	879	9 (1.0%)	116 patients pronounced in field excluded; 3 neurologically intact
Battistella et al[9]	Blunt, penetrating	604	16 (2.7%)	All patients included; 7 neurologically impaired
Fulton et al[22]	Blunt, penetrating	245	6 (2.4%)	Only included those patients transported to hospital
Pasqualeet al[14]	Blunt, penetrating	106	3 (2.8%)	Only included those patients transported to hospital
Willis et al[23]	Blunt, penetrating	89	4 (4.5%)	Only included those patients transported to hospital
Cera et al[7]	Blunt, penetrating	195	53 (27.2%)	Only included those patients transported to hospital
Lockey et al[24]	Blunt, penetrating	909	68 (7.5%)	Only included air transported patients
Pickens et al[13]	Blunt, penetrating	266	14 (5.3%)	Only included patients transported to hospital

212 patients who had asystole and no long-term survivors among patients with PEA and a heart rate less than 40, although 5 of 134 were admitted. All 16 survivors came from the group including those with a heart rate of more than 40 beats per minute. Stratton and colleagues[21] also found that all neurologically intact survivors had PEA with an underlying rhythm of sinus tachycardia or normal sinus rhythm. On the other hand, Cera and coworkers[7] found that PEA with an underlying sinus rhythm was predictive of better survival but 11 survivors had PEA (20.7% of survivors) and 3 survivors had ventricular dysrhythmias (5.7%). Finally, Pickens and colleagues[13] found that an underlying rate of 40 or greater showed improved survival, although 43% of survivors had a rate of less than 40. Also, none of the patients who required defibrillation in the emergency department survived. This final point may reflect that patients with multiple traumatic cardiac arrests have a uniformly poor prognosis.[23]

Duration of CPR

There is significant evidence to suggest that the duration of chest compressions may have an impact on the outcome of traumatic cardiopulmonary arrest. Mattox et al[27] reviewed 100 consecutive cases of trauma (37 blunt and 63 penetrating) in patients who received more than 3 minutes of CPR. There were no survivors in these patients. One intriguing finding was the presence of fatal air embolism in the coronary arteries on autopsy in 12 patients with lung parenchymal injury. Durham and colleagues[28] noted a statistical difference in CPR time for survivors of stab wounds, gunshot wounds, and blunt trauma. They proposed a limit of 5 minutes for patient viability following trauma cardiopulmonary arrest. Pasquale et al[14] supported these findings in 89 patients who underwent more than 5 minutes of CPR following blunt or non-thoracic penetrating trauma. There were no survivors in this population. The two survivors in the Pasquale and coworker's study[14] both had CPR of less than 5 minutes and survived neurologically intact. Fulton et al[22] found no survivors among those patients who had CPR performed for longer than ten minutes or who sustained multiple cardiac arrests. However, they concluded that CPR should not be performed for longer than 30 minutes without response. This agrees with the findings of Falcone et al;[11] in their study of air transported patients, the average time of CPR was 33 minutes. There were no survivors in their study. On the other hand, more recent work by Pickens and colleagues[13] demonstrated that 3 of their 14 survivors had CPR in progress for more than 15 minutes. This last study suggests that although shorter duration of CPR is associated with better survival, prolonged CPR does not preclude a successful outcome. Fialka and coworkers[29] showed that the average duration of closed chest CPR was 13 minutes (range, 11-15 minutes) among their surviving patients.

Advanced Life Support (ALS) Measures

The role of prehospital ALS, including airway management and intravenous access, has been hotly debated in the trauma literature. The role of specific interventions, particularly endotracheal intubation, has been considered with regard to outcome from traumatic cardiopulmonary arrest. Copass et al[30] reported on 131 patients who required CPR following traumatic injury. They found that survivors were more likely to have successful endotracheal intubation (97% versus 65%) and intravenous access (100% versus 70%). They concluded that advanced life support skills improved outcome. Durham et al[28] also supported the use of prehospital intubation demonstrating that 58% of survivors of stab wounds and 67% of gunshot wound survivors underwent field intubation. This compared to 31% and 41%, respectively, among non-survivors. There were no survivors among the 30% of patients with blunt trauma who underwent field intubation. Fulton,[22] however, found 5 survivors among 189 (2.6%) who had prehospital intubation versus 1 survivor (1.8%) among patients intubated in the resuscitation suite.

Rosemurgy and colleagues[5] reported that more than 50% of their patients had scene times in excess of 20 minutes for intubation, intravenous access, extrication, and patient packaging. They had no survivors in their study, suggesting that advanced life support measures conveyed no advantage in their patients. Stratton et al[21] reported that none of the 3 neurologically intact patients with traumatic cardiopulmonary arrest who survived (all with penetrating trauma) had field intubation, despite that 83.1% of victims with penetrating trauma were intubated. Cera et al[7] found that field intubation had no impact on survival from traumatic cardiopulmonary arrest; it was performed in 53.8% of survivors and 73.4% of non-survivors. Perron et al[31] looked at prehospital intubation in pediatric patients and found that there was a significant reduction in mortality when comparing survival in all admitted patients (29%) versus those with prehospital intubation (19%).

Thus, the role of prehospital advanced life support measures remains controversial as it relates to the treatment of traumatic cardiopulmonary arrest. It is expected that field intubation may be helpful for primary etiologies with airway compromise such as hanging or high cervical injuries but may serve to prolong scene time and duration of CPR when performed to the exclusion of other measures. Support for intubation in the pediatric population is limited. Intravenous access is less well studied as it impacts outcome from traumatic cardiopulmonary arrest.

Air Medical Transport

The use of air medical transport for traumatic cardiopulmonary arrest has been examined by several authors. Wright and colleagues[32] evaluated the use of air transport in 67 trauma patients who sustained a cardiac arrest either before or during transport. In this group, there were 86.6% blunt trauma patients. Twenty patients (29.9%) were pronounced dead on-scene. Forty-seven were transported, of which only 6 responded with a pulse. All 47 patients died. Autopsies were available in 66 cases, 61 demonstrated major head injury, cervical spine injuries, or major thoracic injury. Rosemurgy et al[5] noted that 91% of patients in their study arrived via air medical transport. As noted above, there also were no survivors in their study. This supports the futility of air medical transport in such cases.

Falcone et al[11] reviewed 320 patients who had cardiopulmonary resuscitation following trauma. Within this group, 88.9% sustained

Table 3. Survival from Traumatic Cardiopulmonary Arrest for Pediatric Patients

AUTHOR	MECHANISM	NO. PATIENTS	NO. SURVIVAL	COMMENT
Sheikh et al[34]	Blunt	27	0 (0%)	Only included patients transported to hospital
Li et al[35]	Blunt, penetrating	957	224 (23.5%)	Included only patients taken to pediatric trauma center
Perron et al[31]	Blunt, penetrating	729	165 (22.6%)	Same database as Li et al
Suominen et al[36]	Blunt, penetrating	121	4 (3.3%)	All EMS trauma arrests
Fisher et al[37]	Blunt	65	1 (1.5%)	Only included patients transported to hospital
Calkins et al[38]	Blunt	25	2 (4%)	Only included patients transported to hospital

blunt injuries and 80% were transported directly from the scene of the injury. Only 6 of 320 (1.9%) patients survived. The average CPR time was 33 minutes. There was no advantage found for mechanism of injury, CPR time, or initial underlying rhythm. An analysis of the 6 survivors revealed that 3 were revived with bystander CPR (calling into question whether they were truly in cardiac arrest) and the 3 others had vital signs upon presenting to an outside emergency department. The recommendation was to use the initial response to resuscitation as a triage tool.

A protocol of using the response to initial resuscitation efforts to activate an air medical response was supported by Margolin and coworkers,[12] who found only 13 survivors among 67 patients who sustained traumatic cardiopulmonary arrest. Blunt trauma was the mechanism of injury in 79% of cases. Twelve of the 13 survivors had a sinus based rhythm on the transport team's arrival. Survivors also had a higher systolic blood pressure and revised trauma score on arrival of the air medical team. These authors concluded that response to initial resuscitation should dictate activation of the air medical team.

Lockey et al[24] described their 10-year experience in direct response to 909 cases of traumatic cardiopulmonary arrest. There were 68 (7.5%) survivors. Seven hundred forty (81.4%) were pronounced dead on-scene. The number of patients transported after resuscitation was 169, of which 131 were ultimately admitted to the hospital. It is unclear what percentage of these 169 patients had a response to resuscitation. These authors noted that patients with primary asphyxiating injury and penetrating trauma with cardiac tamponade had a better rate of survival.

Finally, DiBartolomeo and colleagues[33] compared outcomes between basic life support-staffed (BLS-staffed) ground EMS units and a physician-staffed helicopter in the outcomes of 129 patients who suffered traumatic cardiopulmonary arrest. The demographic distribution between the 56 patients treated by helicopter crews and 73 patients treated by ground crews were similar with regard to mechanism of injury and gender. There was a statistically but not clinically significant difference in age. There were no survivors treated by ground BLS response and 2 (3%) survivors of those treated by physician-staffed helicopter crew. Both patients were neurologically impaired. These authors suggested that larger scale studies would need to be performed to determine the efficacy of air medical response.

These studies suggest that the use of air medical transport is not futile but should be limited to patients who have a response to initial resuscitation on-scene or within the referring hospital.

Pediatric Patients

Although in general, age and gender have not been shown to be a factor in survival from traumatic cardiopulmonary arrest, it is reasonable to consider whether pediatric patients have a better outcome than adult patients. *(See Table 3.)* Sheikh and Brogan[34] reported on their 5-year experience with blunt trauma victims receiving both open and closed chest CPR. All patients were in cardiac arrest at the time of presentation. All but 4 of the patients were in asystole at the time of presentation to the trauma center, although 8 patients had PEA with a sinus rhythm when first treated by EMS. The mean CPR time was between 7 and 8 minutes. Despite that 15 patients received open thoracotomy at the time of presentation, no patient survived to discharge.

Pediatric traumatic cardiopulmonary arrest also was investigated by Li et al[35]who reported on 957 patients who underwent CPR either prior to or upon admission to pediatric trauma centers reporting to the National Pediatric Trauma Registry. Of these cases, there were 224 (23.5%) survivors. There was an almost universally dismal prognosis for patients with an asystolic rhythm on arrival (1 of 87 survived). Other factors that were associated with poor outcome included: systolic blood pressure less than 60 mmHg, comatose state, penetrating trauma, and need for CPR upon admission. Sixty-four percent of survivors had some functional disability. The data from the National Pediatric Trauma Database was further examined by Perron and colleagues,[31] who also reported survival in 25% of their study subjects. They confirmed poor outcome in patients with penetrating trauma and those children requiring additional CPR. In addition, prehospital intubation was associated with a worse outcome than that seen in those children who arrived unintubated. It should be remembered that both these results may be influenced by selection bias as out-of-hospital deaths as well as pediatric trauma arrests transported to non-trauma hospitals were not included.

Suominen et al[36] presented a more dismal picture in their 10-year review of pediatric traumatic cardiopulmonary arrest. They reviewed the outcomes of 41 pediatric patients with cardiac arrest, although 15 were secondary to smoke inhalation, strangulation or electrocution. Of the 26 remaining patients, 23 suffered a blunt injury and 3 suffered penetrating injury. Two of the 26 patients survived (7.7%), with only one who was neurologically intact. Only one of 21 patients whose initial rhythm was asystole survived. No trauma patient who arrived without vital signs survived.

Fisher and coworkers[37] described their 12-year experience with 65 victims of blunt traumatic cardiopulmonary arrest in pediatric patients. Sixty-four (99%) of these patients expired, with 61 (93.8%) dying within the first 24 hours of admission. No patient survived neurologically intact. Of the 36 patients who had an autopsy, 31 had lethal cranial and cervical injuries, 16 had lethal abdominal injuries, and 12 had lethal thoracic injuries (myocardial rupture, aortic or vena caval disruption).

Most recently, Calkins and colleagues[38] described their experience with 25 children with traumatic cardiopulmonary arrest during a 3-year period. Sixty-four percent had CPR during transport, whereas 36% had CPR started in the resuscitation area. There were 2 survivors (8%), both of whom had CPR started in the trauma suite. Twenty-one patients died from severe head or spinal cord injury. Only 2 of 23 deaths (9%) were due to exsanguinating hemorrhage. Neither survivor had associated head injury or any neurologic sequelae on discharge.

These studies suggest that children have not been as well studied as adult populations but appear to have an equally dismal prognosis.

NAEMSP/COT Recommendations. Traumatic cardiopulmonary arrest, in general, has had a very dismal prognosis; this led the National Association of EMS Physicians and the American College of Surgeons Committee on Trauma to develop a joint position paper[39] that discusses a rational and measured approach to patients who sustain a cardiac arrest after trauma. These recommendations attempt to incorporate many of the findings cited above and also have incorporated much of the literature addressing emergency thoracotomy (cited later in this text). The full recommendations can be found online at: *www.naemsp.org/pdf/guideterminate.pdf*. In short, the recommendations were offered to provide guidance to health care providers who attend to victims of traumatic cardiopulmonary arrest and define situations where such efforts may be futile, costly, and risky.

At least three studies have specifically evaluated the NAEMSP/COT recommendations. Pickens[13] compared the clinical circumstances for each of their 14 survivors and found that 13 would not have undergone resuscitation if their system had utilized these recommendations. They had two surviving blunt trauma victims who were pulseless, apneic, and without an organized rhythm on presentation. Two victims of penetrating trauma were initially in asystole. Three survivors had documented CPR times in excess of 15 minutes. Willis et al[23] noted that two of their 4 surviving patients who have qualified for termination of resuscitation efforts in the field had the NAEMSP/COT guidelines been utilized. Finally, Lockey et al[24] found that 13 (36%) of their 36 survivors would have breached the guidelines had they been strictly applied. This included 5 surviving blunt trauma victims who were pulseless, apneic, and without an organized rhythm; one patient with penetrating trauma who was apneic, pulseless and without signs of life; and 7 survivors whose cardiac arrest was witnessed and resuscitation efforts exceeded 15 minutes without response. Thus it appears that the current NAEMSP/COT recommendations are not 100% sensitive in identifying patients likely to fail resuscitation efforts.

Prehospital Care of Traumatic Cardiopulmonary Arrest

Based on the information provided above, it appears that there may be no absolute recommendations that can be made regarding the out-of-hospital disposition of patients with traumatic cardiopulmonary arrest. However, there are some treatment recommendations that can be made based on the likely causes of early trauma arrest and considering those conditions that may be potentially reversible. *(See Figure 1.)* These recommendations should be consistent with the treatment algorithms proposed in the International Trauma Life Support (ITLS), Prehospital Trauma Life Support (PHTLS), and Advanced Trauma Life Support (ATLS) courses. Continued support of the patient with traumatic cardiopulmonary arrest with chest compressions and other advanced cardiac life support is essential despite evidence that chest compressions themselves can be harmful.[25]

Airway with Cervical Spine Control and Ventilatory Assistance. Given that there are many causes of early death in which both the airway and cervical spine may be at risk, it seems reasonable to emphasize the establishment of a patent airway. Airway compromise from head injury, drug and alcohol intoxication, vomitus, and secretions, as well as direct airway injury, may lead to early death. Although airway compromise is the third leading cause of traumatic cardiopulmonary arrest behind craniocervical injury and thoracic vascular injury,[40] it must remain the first priority in approaching the patient.

Basic airway maneuvers should be emphasized first, including the jaw-thrust maneuver, neutral head positioning, and adequate suctioning of the airway. As demonstrated in the previous discussion, the role of prehospital endotracheal intubation in patients with traumatic cardiopulmonary arrest remains controversial. The discussion in these patients parallels recent concerns raised by other authors about the application of this skill in the out-of-hospital treatment of both adults[41,42] and children.[43] Prehospital intubation is probably most effective in the hands of providers who use it frequently, have continued training in this skill, and who are capable of completing this task quickly and competently.

The role of alternative airways such as the laryngeal mask airway, Combitube, pharyngeotracheal lumen airway, or newer single lumen airways (e.g., King LT) in this setting needs to be explored.

Restoration of Circulating Blood Volume. Since major thoracic vascular injury is a major cause of out-of-hospital death and thoracoabdominal hemorrhage is implicated in early in-hospital death, it is essential that intravenous access be established and fluid replacement be initiated to provide any hope of success.

With regard to vascular access, care must be taken to minimize the time on-scene in patients with traumatic cardiac arrest. The current recommendation for any trauma patient is to have two large bore intravenous catheters inserted with crystalloid solutions infusing as rapidly as possible. However, the benefit of this therapy must be weighed against the time consumed establishing vascular access.[44] Intravenous access should not delay transport to an ED, especially in an urban setting. When transport times are longer (rural settings), IV fluids become more important and a minimal delay in transport becomes less important in comparison.

Although there is significant debate about permissive hypotension particularly in the setting of penetrating trauma,[45] establishing a measurable blood pressure must remain a goal in the trauma arrest victim. At least one study has suggested that a systolic blood pressure of greater than 60 mmHg upon arrival to the hospital confers a survival advantage for victims of traumatic cardiopulmonary arrest.[28]

The current resuscitation fluid recommendation remains a crystalloid solution of either normal saline or lactated Ringer's solution. Blood substitutes may be a promising alternative in the future but recent trials have been hindered by ethical concerns.[46] The use of hypertonic saline has been explored in both military[47] and civilian[48] settings as a more efficient method of restoring circulating blood volume in the setting of early shock. However, there is not sufficient evidence to conclusively support the use of this agent in the routine management of profound blood loss or traumatic cardiopulmonary arrest.

Focusing on vascular access, intraosseous infusion remains a viable option that can be established rapidly[49] and provide for rapid infusion of virtually any resuscitation fluid at rates approaching large bore peripheral intravenous lines. Sites for insertion most commonly include the sternum and proximal femur; alternative sites, including the femur and proximal humerus, also have been used. The proximal tibia seems to be ideal since it is located away from the thorax where chest compressions are provided and the landmarks are easily identified. Lower extremity fractures may preclude the use of this site and complications such as compartment syndrome and osteomyelitis must be considered.

Other Interventions. In reviewing other potentially reversible causes of traumatic cardiac arrest, both tension pneumothorax and cardiac tamponade must be considered. The classic findings of tension pneumothorax, including distant or absent breath sounds, tympany on percussion of the involved hemithorax, neck vein distention, and tracheal deviation, may be difficult to appreciate in the out-of-hospital setting. The most reliable finding is difficult ventilation of these patients. Treatment of this condition in the out-of-hospital setting relies primarily upon needle decompression of the involved pneumothorax by insertion of a catheter into the second intercostal space. Some prehospital protocols will call for empiric needle decompression of both hemithoraces in all cases of traumatic cardiopulmonary arrest based on limitations in the physical assessment of these patients. Several case reports have noted that needle catheters were not effective in relieving a tension pneumothorax.[50,51] One prospective study addressed the effectiveness of this maneuver and concluded that needle decompression is of limited efficacy.[52] However, if accomplished quickly and effectively, there is essentially no added risk to the patient, who is already "dead" and has very little else to loose.

Several studies have noted that patients with pericardial tamponade have a favorable prognosis if identified early.[53-55] Here again, the classic signs of tamponade, including muffled heart tones and distended neck veins, may be difficult to appreciate in the prehospital setting. Decompression of cardiac tamponade using a subxyphoid approach has been taught in some prehospital texts and has been in use by EMS systems. However, data on the utility of this procedure in major cardiac injury indicate that it is not effective.[56,57] Contrary to needle decompression for suspected tension pneumothorax, a significant pericardial tamponade resulting in a cardiopulmonary arrest will almost certainly require a pericardiotomy for relief and control. In this instance, even a delay of a few moments can make the difference between life and death. If a cardiac tamponade is suspected and the patient is in an urban environment, transport should be the primary consideration.

Rapid Transport. There is no doubt that the duration of cardiac arrest has an impact both on patient mortality and long-term disability of survivors. In addition, the limited success of emergency thoracotomy depends on the timely delivery of a potentially salvageable patient. Each prehospital system should develop specific policies regarding the treatment and transport of patients with traumatic cardiopulmonary arrest based on their level of training, availability of providers with advanced skills such as air medical transport, proximity to the nearest emergency department, and proximity to the nearest trauma center. In urban environments, rapid transport with minimal intervention to the area trauma center is the most efficacious strategy. In more suburban environments, transport to the nearest hospital for stabilization and secondary transport to a trauma center may be the preferred strategy. Air medical support can be instrumental in accomplishing such secondary transfers.[12] The more challenging situations arise in rural locations where there is limited access to a trauma center, where transport times to the nearest hospital can be prolonged and where the provider may be capable of basic life sup-

Figure 1. Prehospital Treatment Guidelines for Traumatic Cardiopulmonary Arrest

ENVIRONMENT	TREATMENT GUIDELINES
Urban	Basic airway and spine protection measures Definitive airway and intravenous access enroute Consider needle decompression of chest Rapid transport — trauma center preferred
Suburban	Basic airway and spine protection measures Consider definitive airway and intravenous access Fluid resuscitation Needle decompression of chest Consider pericardiocentesis (if allowed by protocol) Rapid transport — nearest hospital
Rural	Consider air medical transport for ALS skills Definitive airway and intravenous access at scene Fluid resuscitation Needle decompression of chest Consider pericardiocentesis (if allowed by protocol) Rapid transport to nearest hospital or consider air medical transport for any response

Figure 2. Treatable Conditions Leading to Traumatic Cardiopulmonary Arrest

CONDITION	TREATMENT
Airway obstruction/compromise	Establish airway
Hypoventilation (spinal cord injury, ruptured diaphragm)	Ventilate
Open pneumothorax	Seal/ventilate
Tension pneumothorax	Decompress
Massive hemothorax (major vascular or cardiac injury)	Resuscitate/control*
Cardiac tamponade	Decompress/repair
Hemoperitoneum (solid organ or vascular injury)	Resuscitate/control
Retroperitoneal hemorrhage	Resuscitate/control
Non-torso exsanguination	Resuscitate/control

* Control of hemorrhage should parallel resuscitation, and will most often require surgical intervention in the unstable patient.

port only. Options in such conditions include use of air medical support to provide advanced procedures; airway stabilization with CPR and advanced life support intercept; and field pronouncement after a period of airway intervention and cardiac compressions. The specific option chosen should be addressed in regional trauma triage protocols.

Hospital Care of Traumatic Cardiopulmonary Arrest

Care of the patient with traumatic cardiopulmonary arrest should be based on the tenets of ATLS, with a focus on the identification and treatment of immediately correctable causes of cardiac arrest. *(See Figure 2.)* Treatment priorities would include establishment of a definitive airway, provision of adequate ventilation, and insertion of chest tubes in patients with tension pneumothorax, massive hemothorax, bronchial or esophageal disruption, or diaphragmatic tear. The patient's volume status should be addressed with the administration of crystalloid solution through large bore peripheral intravenous catheters. Larger infusion catheters may be utilized and early autologous and allogeneic blood transfusion also can be considered. Either a FAST exam or diagnostic peritoneal lavage should be performed to diagnose massive hemoperitoneum. The focused abdominal sonography in trauma or FAST examination has the advantage of providing information about possible pericardial tamponade and cardiac injury. Immediate radiographs of the pelvis should be obtained to detect massive retroperitoneal hemorrhage.

However, the major decision that must be made in cases of traumatic cardiopulmonary arrest is whether to perform an emergency thoracotomy. This procedure was originally described in 1897 by Rehn[58] and was rediscovered for management of traumatic cardiac arrest in the 1960s.[59,60] The procedure is performed using a left anterior lateral approach after the patient's chest has been rapidly prepped. In about 20% of cases,[61] the incision will require an extension across the right chest to control hemorrhage. The major steps involved once the chest has been opened include: 1) direct control of any cardiac or vascular injuries; 2) identification and relief of pericardial tamponade via pericardiotomy; 3) maintenance of major organ perfusion via cross-clamping of the thoracic aorta; 4) maintenance of forward blood flow by open cardiac compression; and 5) cross-clamping the pulmonary hilum to control of air embolism. None of these subprocedures are easy. They all require training and practice. A discussion of the technique of ED thoracotomy and the credentialing of the provider are beyond the scope of this paper. Both, however, should be discussed and decided in advance.

Outcomes studies on emergency thoracotomy have been hampered by the same problems that have beset studies of prehospital cardiopulmonary arrest. They include a lack of uniform definitions and endpoints, as well as selection bias for patients taken to trauma centers. More specifically, emergency thoracotomy has been studied in a variety of disparate situations, including not only those procedures performed on the patient arriving without a pulse, but also those who lose a pulse either in the emergency department or operating suite, those who remain persistently hypotensive despite adequate resuscitation, and even those who undergo thoracotomy for ongoing thoracic hemorrhage.

The most comprehensive review on this subject was conducted by Rhee and colleagues[62] in 2000. These authors considered only studies in which both penetrating and blunt trauma were included. Their analysis focused on true emergent thoracotomies defined as those performed in the emergency department or trauma resuscitation area. The authors examined the factors that contributed to a successful discharge from the hospital and normal neurologic outcome. Twenty-four studies from 1974 through 1998 were included in their meta-analysis. The overall survival rate was 7.4% for the 4620 thoracotomies reported in this study. The survival range was from 1.8% to 27.5% depending on patient selection. Nine of the 24 studies had survival rates in excess of 10% of eligible patients. These authors demonstrated survival rates of 1.4% for blunt trauma victims, 4.3% for gunshot wounds, and 16.8% for stab wounds. Isolated cardiac injury had a survival rate of 19.4%, whereas patients with multiple injury sites had a survival of 0.7%.

The data also were examined for patients who lost signs of life, defined as cardiac electrical activity (organized cardiac rhythm), respiratory effort, or pupillary response. Patients who lost signs of life in the field had a survival of 1.2% compared to 8.9% for those who arrested during transport or 11.5% who demonstrated signs of life on arrival and subsequently arrested during resuscitation.

Although neurologic outcome was not routinely reported, survivors were neurologically normal 92.7% of the time when reported. Based on Rhee and coworkers'[62] analysis, the following recommendations for emergency thoracotomy were made: 1) it should be performed for victims of penetrating trauma with signs of life in the field not responding to fluid resuscitation or those who lose vital signs during resuscitation; 2) it should be performed for patients with penetrating injury with any sign of life in the field who is in traumatic cardiopulmonary arrest on arrival;

3) it should be performed for patients with blunt trauma who lose signs of life in the resuscitation area or immediately prior to arrival (not further defined); and 4) no emergency thoracotomy be attempted on patients who arrive without signs of life who did not have signs of life in the field. The authors did acknowledge, however, that there is no uniform predictor of mortality.

Fialka et al[29] supported the recommendation regarding performance of an emergency thoracotomy in blunt trauma victims who lose signs of life immediately before arrival. They reported 4 survivors out of 38 blunt trauma patients who had CPR for between 11 and 15 minutes prior to thoracotomy. Only one of these survivors had signs of life on arrival to the resuscitation area. Coats et al[48] confirmed that only penetrating victims with signs of life at the scene are amenable to emergency thoracotomy. There were no survivors among their patients with penetrating injury who did not demonstrate any signs of life on-scene.

More recently, Powell et al[63] shed further light on these recommendations. They reported on 26 survivors among 959 patients who underwent emergency thoracotomy. Only 4 survivors sustained blunt trauma and the maximum duration of prehospital CPR was 5 minutes. No survivor of penetrating trauma had prehospital CPR of more than 15 minutes. These authors reported 5 survivors with an initial rhythm of asystole which had been thought to be a uniformly poor prognostic indicator. Each of these patients had pericardial tamponade. Kennedy and Sharif[64] reviewed their personal experience in performing over 100 emergency thoracotomies. They reported that only 7 survived to discharge. All were victims of penetrating injury and no survivors were in traumatic cardiopulmonary arrest upon arrival of paramedics. This author has also advocated against the use of abdominal cross-clamping in performing an emergency thoracotomy and withholding the procedure for those in cardiac arrest for more than 20 minutes. Finally, Sheppard et al[65] advocated for one additional indication for emergency thoracotomy: traumatic cardiopulmonary arrest from non-torso injury. In their series of 959 patients undergoing emergency thoracotomy, 27 had non-truncal trauma. Three of 27 (11%) survived.

Pediatric patients who undergo emergency thoracotomy have demonstrated mixed results. Beaver et al[66] had no survivors among 15 children with blunt trauma patients and 2 with penetrating trauma who underwent emergency thoracotomy. Powell and colleagues,[67] however, demonstrated 4 survivors (36%) among 11 children with penetrating injury and cardiac arrest as well as one survivor (12.5%) among the 8 blunt injury victims.

These results suggest that ideally emergency thoracotomy should be performed within 5 minutes of losing vital signs for victims of blunt trauma and 15-20 minutes for victims of penetrating trauma. Special consideration should be given to victims of non-torso trauma. Emergency thoracotomy should not be undertaken for trauma victims who had no signs of life in the field and have not responded to resuscitative efforts both in the field or following initial assessment in the resuscitation area. *(See Figure 3.)*

One special consideration that must be discussed is the care of the pregnant female who has sustained a traumatic cardiopulmonary arrest. In this setting, a rapid decision must be made with regard to performing a perimortem cesarean section. The decision should be based on gestational age and fetal viability ex-utero, and the duration of cardiopulmonary arrest. Katz and coworkers[68] first introduced the term "perimortem cesarean section" and suggested that there was a 4-minute limit to fetal viability. This short interval was determined based on the limited cardiac output produced during CPR in pregnancy due to caval compression by the uterus. Since that time, there have been multiple case reports of viable infants being delivered in the perimortem period.[69,70] A recent series from Katz et al[71] described 38 cases of perimortem cesarean section in the literature from 1986-2004. The leading cause of death was maternal trauma. The authors suggest that the period of viability extends far beyond the 4 minute limit. In fact, 7 of 38 cases described had the procedure performed after 15 minutes of CPR and the infant was neurologically intact in 4 cases. This suggests that although the decision to perform an emergent perimortem cesarean section must be made rapidly, the previous limit of 4 minutes to perform the procedure appears to be arbitrary.

Figure 3. Recommendations for Performing an Emergency Thoracotomy

1. **Blunt Trauma:** Emergency thoracotomy should be performed within 5 minutes of vital sign loss.
2. **Penetrating Trauma:** Emergency thoracotomy should be performed within 15 to 20 minutes of vital sign loss.
3. **Non-torso Trauma:** Special consideration should be given to performing an emergency thoracotomy in victims with cardiac arrest.
4. **No Signs of Life in the Field:** Emergency thoracotomy should not be undertaken for trauma victims who have not responded to resuscitative efforts either in the field or following initial assessment in the resuscitation area.

Conclusion

Almost 80% of trauma deaths occur in the first few hours following injury. Therefore, it is likely that many prehospital, emergency department, and general surgery practitioners will encounter patients with traumatic cardiac arrest in their practices. Although neurologically intact survival is rare, survival from traumatic cardiopulmonary arrest is not unknown. Studies have shown that the resources dedicated to the care of these patients and the costs incurred may be offset by the return in productivity achieved by these rare survivors.

Prehospital providers must be aware of their treatment options and limitations in caring for victims of traumatic cardiopulmonary arrest. The closer in proximity one is to a trauma center, the less intervention there is to be performed on-scene. Rural providers are hindered by longer transport times and limited advanced skills. Air medical teams should be considered a potential resource in this environment.

In the hospital, initial efforts should be focused on establishing a definitive airway and intravenous access and on identification of immediately treatable conditions. Successful resuscitation must be coupled with hemorrhage control. A rapid decision must be made regarding the benefit of emergency thoracotomy. Blunt trauma patients with more than 5 minutes of CPR and penetrating trauma victims with more than 15 minutes of CPR are unlikely to survive. The pregnant trauma patient with a viable fetus should be considered for a perimortem C-section.

Although victims of traumatic cardiopulmonary arrest with penetrating trauma, signs of life on arrival to the resuscitation area, and an underlying non-perfusing sinus rhythm have a better outcome, there are no absolute predictors of survival.

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CNE/CME Objectives

Upon completing this program, the participants will be able to:

a.) discuss conditions that should increase suspicion for traumatic injuries;

b.) describe the various modalities used to identify different traumatic conditions;

c.) cite methods of quickly stabilizing and managing patients; and

d.) identify possible complications that may occur with traumatic injuries.

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Physicians and nurses participate in this continuing medical education/continuing education program by reading the article, using the provided references for further research, and studying the questions at the end of the article. Participants should select what they believe to be the correct answers, then refer to the list of correct answers to test their knowledge. To clarify confusion surrounding any questions answered incorrectly, please consult the source material. **After completing this activity, you must complete the evaluation form provided and return it in the reply envelope provided in order to receive a letter of credit.** When your evaluation is received, a letter of credit will be mailed to you.

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CME/CNE Questions

1. Major causes of prehospital trauma deaths include:
   A. major head injury.
   B. Spinal cord injury.
   C. traumatic aortic rupture.
   D. All of the above

2. A patient with which of the following initial cardiac rhythms is least likely to survive?
   A. PEA
   B. Ventricular fibrillation
   C. Asystole
   D. Sinus tachycardia

3. Shorter duration of CPR is associated with better survival, but prolonged CPR does not preclude a successful outcome.
   A. True
   B. False

4. Which of the following is true regarding ALS measures for prehospital traumatic cardiopulmonary arrest?
   A. Survivors were more likely to have successful endotracheal intubation and intravenous access.
   B. Long scene times led to better outcomes.
   C. All pediatric patients in traumatic cardiopulmonary arrest should be intubated.
   D. The value of field intubation is clear.

5. Studies suggest that the use of air medical transport is not futile, but should be limited to patients who have a response to initial resuscitation on-scene or within the referral hospital.
   A. True
   B. False

6. Pediatric traumatic cardiopulmonary arrest has been well studied and is associated with a better outcome than that found with adults.
   A. True
   B. False

7. The current resuscitation fluid of choice is:
   A. blood substitutes.
   B. crystalloid solution.
   C. hypertonic saline.
   D. colloids.

8. Which of the following is a recommended treatment guideline in a rural setting?
   A. Consider air medical transport for ALS skills
   B. Definitive airway and intravenous access at the scene
   C. Fluid resuscitation
   D. All of the above

9. Which of the following is a recommendation for performing emergency thoracotomy?
   A. Emergency thoracotomy should be performed within 45 minutes of vital sign loss for blunt trauma patients.
   B. Emergency thoracotomy should be performed within 15-20 minutes of vital sign loss for penetrating trauma patients.
   C. Emergency thoracotomy should be performed on patients who do not respond to resuscitative efforts in the field.
   D. Emergency thoracotomy should be performed on patients who do not respond to resuscitative efforts in the initial assessment in the ED.

10. Which of the following is true regarding the care of the pregnant trauma patient in cardiopulmonary arrest?
   A. Perimortem C-sections should never be performed.
   B. The decision to perform a perimortem C-section should consider gestational age and fetal viability.
   C. The leading cause of fetal death is direct fetal trauma.
   D. A perimortem C-section should never be considered after 4 minutes.

Answers: 1. D; 2. C; 3. A; 4. A; 5. A; 6. B; 7. B; 8. D; 9. B; 10. B

In Future Issues:

Pitfalls in Trauma Management

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2. describe the various modalities used to identify different traumatic conditions
3. cite methods of quickly stabilizing and managing patients
4. identify possible complications that may occur with traumatic injuries

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This issue includes an evaluation form to complete and return in an envelope we have provided. Please make sure you sign the attestation verifying that you have completed the activity as designed. Once we have received your completed evaluation form we will mail you a letter of credit. This activity is valid 24 months from the date of publication. The target audience for this activity is emergency medicine physicians and nurses, trauma surgeons and nurses.

Those participants who earn nursing contact hours through this activity will note that the number of contact hours is decreasing to 9 annually. This change is due to the mandatory implementation of a 60-minute contact hour as dictated by the American Nurses Credentialing Center. Previously, a 50-minute contact hour was used. AHC Media LLC is accredited as a provider of continuing nursing education by the American Nurses Credentialing Center's Commission on Accreditation.

If you have any questions about the process, please call us at (800) 688-2421, or outside the U.S. at (404) 262-5476. You can also fax us at (800) 284-3291, or outside the U.S. at (404) 262-5560. You can also email us at: customerservice@ahcmedia.com.

On behalf of AHC Media, we thank you for your trust and look forward to a continuing education partnership.

Sincerely,

Brenda Z. Mooney

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