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Review

The use of emergency department thoracotomy for traumatic cardiopulmonary arrest

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ABSTRACT

Despite the establishment of evidence-based guidelines for the resuscitation of critically injured patients who have sustained cardiopulmonary arrest, rapid decisions regarding patient salvageability in these situations remain difficult even for experienced physicians. Regardless, survival is limited after traumatic cardiopulmonary arrest. One applicable, well-described resuscitative technique is the emergency department thoracotomy—a procedure that, when applied correctly, is effective in saving small but significant numbers of critically injured patients. By understanding the indications, technical details, and predictors of survival along with the inherent risks and costs of emergency department thoracotomy, the physician is better equipped to make rapid futile versus salvageable decisions for this most severely injured subset of patients.

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Introduction

The injured patient presenting in extremis poses a clinical, administrative, and philosophical dilemma to the practicing surgeon. While the role of cardiopulmonary resuscitation (CPR) in cardiac arrest victims is well described, the use of conventional CPR in traumatic arrest victims is usually ineffective. As an "extension" of CPR, emergency department thoracotomy (EDT) has improved survival in select patients with life-threatening injuries. Despite limited survival after traumatic arrest, these resuscitative techniques may offer the only hope for the survival of critically injured patients and remain widely practiced.

Cardiopulmonary resuscitation in trauma

Injury is the leading cause of death in the United States among those ages 1–44 years.[1] Of these, 34% will die prior to hospital arrival.[1] Numerous studies have documented that pre-hospital traumatic arrest in any injured patient, regardless of mechanism, is associated with poor survival.[2–13] After excluding patients with injuries deemed incompatible with life, Rosemurgy reviewed

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138 patients with traumatic arrest due to both blunt and penetrating injuries prior to hospital arrival.[11] Despite maximal resuscitation, there were no survivors in this group. Pasquale et al. analysed 106 injured patients requiring prehospital CPR to find 3 survivors.[9] Battistella et al. reviewed over 600 injured patients who required prehospital CPR.[2] Sixteen survived their hospitalisation, of which 7 had suffered severe neurological impairment. Interestingly, most of the survivors suffered penetrating injuries and all had measurable vital signs in the field.

Based on the results of these and other reports, the National Association of Emergency Medical Services Physicians (NAEMSP) and the American College of Surgeons Committee on Trauma established guidelines in 2001 for the termination of pre-hospital CPR in trauma patients.[14] By analysing predictors of outcome such as mechanism of injury, initial cardiac rhythm, duration of pre-hospital CPR and field resuscitation time, these guidelines delineate which patients are unlikely to benefit from further resuscitative efforts.

Several studies have examined the relationship between mechanism of injury and survival in trauma patients requiring CPR. In 2006, Lockey et al. concluded that patients whose cardiac arrest resulted from hypoxemia survived more often than either blunt or penetrating trauma patients.[15] Stockinger and McSwain also determined that patients with a hypoxic mechanism had improved survival (13%) in their review of 588 trauma patients requiring CPR.[16] Battistella et al. found a 4% survival rate in penetrating trauma patients compared to a 1.3% survival rate in patients requiring prehospital CPR after blunt injury.[2] Overall, patients that have suffered cardiac arrest following a hypoxic insult or penetrating injury survive more often than those sustaining blunt injuries.

Markers of physiologic derangement, closely related to injury mechanism and anatomic injury, are important predictors of survival after prehospital traumatic arrest. Initial field cardiac rhythm is a well-studied prehospital clinical variable determined to be predictive of survival and outcome. In the Battistella series, 346 patients were discovered by EMS personnel to be asystolic or agonal with heart rates less than 40 beats per minute. None survived until hospital discharge.[2] The authors concluded that either asystole, pulseless electrical activity (PEA) or agonal rhythms with a heart rate less than 40 beats per minute may be a simple and effective triage "cutpoint" value that will help EMS personnel quickly determine which patients need rapid transport to a trauma centre and which may be considered nonsalvageable. Other authors have reported conflicting results though. Pickens et al. found that 4 of these 14 survivors of prehospital traumatic cardiopulmonary arrest were asystolic or in PEA with a heart rate less than 40 beats per minute on initial EMS obtained cardiac monitoring.[10] Most recently, Schuster et al. reviewed 25 patients presenting to their level I trauma centre in PEA arrest from either blunt or penetrating mechanisms—only three patients survived beyond the emergency department and 2 of these 3 survivors were treated for tension pneumothoraces.[17] Despite conflicting reports, the presence of a sustainable cardiac rhythm in the field clearly portends a survival advantage to the critically injured patient.

Duration of prehospital traumatic cardiopulmonary arrest, as measured by duration of prehospital CPR, is also reliable predictor of outcome. Pasquale et al. used duration of prehospital CPR as a triage tool to define patients as "dead on arrival" or salvageable.[9] Blunt injured patients who underwent prehospital CPR for greater than 5 min without a return of pulse were deemed DOA. Patients with penetrating injuries were considered DOA after 5 min of prehospital CPR with injuries to the head, neck, abdomen, or extremities, while patients were considered DOA with thoracic injuries only after 15 min of prehospital CPR without pulse return. Utilising these criteria, the authors considered 86 patients DOA and reported 3 survivors of 20 patients who were resuscitated. The estimated cost saving to their hospital was substantial at greater than $250,000. Other authors have reported similar results. Mattox and Feliciano reviewed 100 patients who underwent greater than 3 min of prehospital CPR to find no survivors.[7]

This focus on patient salvageability through survival predictors has not improved outcomes however, as the resuscitation of prehospital cardiopulmonary traumatic arrest victims with traditional CPR is largely ineffective. Overall, 0–25% of those requiring pre-hospital CPR survive their hospitalisation.[1–17] Emergency department thoracotomy, when patients are properly selected, is an extension of CPR that may improve survival in these most critically injured patients.

Emergency department thoracotomy

Emergency department thoracotomy (EDT) is an extension of pre-hospital CPR that has remained controversial since its inception in 1896 when Rehn performed the first thoracotomy and cardiorrhaphy for a patient with pericardial tamponade due to a right ventricular stab wound.[18] Despite numerous reports over the following century describing improved survival with mandatory early operative treatment for penetrating thoracic injuries, the first formal report of immediate ED thoracotomy for the moribund trauma patient was described by Beall in 1967.[19] The applicability of EDT was further broadened in 1976 when Ledgerwood described prelaparotomy thoracotomy with aortic occlusion for abdominal exsanguination.[20] Since this time, many groups have attempted to discern which patients are likely to benefit most from EDT.[21–46]

Predictors of EDT survival

Over the past 20–30 years, a large volume of work has been dedicated to determining predictors of survival and outcomes after EDT. Thoroughly studied variables include injury mechanism, anatomic injury, and degree of prehospital and emergency department physiologic compromise.

As in prehospital traumatic arrest, injury mechanism is an important predictor of EDT outcome. Over the past 40 years of EDT literature, survival rates described after blunt injury have been uniformly dismal. In a compilation of 25 years of EDT literature, Rhee et al. reported an overall 7.4% survival rate in over 4600 patients who underwent EDT for either blunt or penetrating mechanisms.[36] When patients were stratified by injury mechanism, 8.8% of those injured by penetrating means survived. Only 1.4% of blunt injured patients survived with many contributing series reporting no survivors. More recently, Moriwaki et al. employed an aggressive approach to the resuscitation of blunt trauma victims that included in-hospital resuscitation for 30 min during which they performed EDT and epinephrine infusion every 3 min.[8] Over 400 patients underwent EDT after blunt trauma and 3% survived to hospital discharge—the majority of which were in a persistent comatose state. Limited survival and poor neurologic outcomes support a restrictive approach to EDT after blunt injury.

The specific type of penetrating injury mechanism also influences EDT survival. Though few would argue that the best EDT survival rates are found after single cardiac stab wounds, interpersonal violence in many urban areas is now largely inflicted by firearms.[39] In Rhee's meta-analysis, 16.8% of patients suffering stab wounds survived EDT, but only 4.3% of those suffering gunshot wounds survived their hospitalisation.[36] Feliciano et al. found a 19.8% survival in stab wounds versus a 3.4% survival in gunshot wounds in their review of 280 patients.[28] In 1998, Branney et al. published the results of a 23-year EDT experience in which survival after cardiac stab wounds was 14.6%. Survival after cardiac gunshot wounds was much lower at 1.8%.[24] More recently, Seamon et al.

evaluated 283 patients who underwent EDT for penetrating cardiac or great vessel injury.[39,40] Patients who sustained cardiac or great vessel gunshot wounds were determined, through multiple variable logistic regression, to be >11 times more likely to die than those sustaining stab wounds (gunshot wounds, 3% versus stab wounds, 24%)—a finding that is consistent with previous work from this author. Importantly, the wounding capacity of commonly used firearms has also changed over time. When semi-automatic handguns with greater muzzle velocity became popular in the mid 1990s, ''ideal'' survival characteristics such as penetrating cardiac injuries became less important as these guns more often created unsalvageable wounds.[39]

Contemporary firearms create larger wounding forces with greater cardiac tissue destruction and larger periocardiotomies leading more often to exsanguination rather than compressive shock created by pericardial tamponade after a cardiac SW. To date, this belief remains largely unproven. Moreno et al.[34] retrospectively reviewed 100 patients with penetrating cardiac injuries (SW, 57%; GSW, 43%) of which 69% underwent EDT. Multivariate logistic regression found pericardial tamponade to be predictive of hospital survival although the majority of their EDT study population comprised stab wound victims. Tyburski et al.[47] retrospectively reviewed 302 patients with penetrating cardiac injuries of which 152 required EDT. Additionally, they found that survival after cardiac GSW was not affected by the presence of cardiac tamponade.

Prospective studies analysing penetrating cardiac injuries and the presence of pericardial tamponade have been reported. Buckman et al.[48] prospectively studied 66 consecutive patients with penetrating cardiac injuries (SW, 30%; GSW, 70%). While pericardial tamponade was found to be associated with SW injuries, the presence of cardiac tamponade itself did not determine survival. Instead, the presence of cardiac SW and the degree of presenting physiologic derangement strongly influenced resuscitation outcomes. Asensio et al.[49] echoed similar findings in a prospective study of 60 patients with penetrating cardiac injuries, 61.7% of which required EDT. Of these 60 patients, 41.7% suffered SW and 58.3% suffered GSW. While the authors found evidence of pericardial tamponade in 83.3% of patients, tamponade once again did not influence outcome. Although the presence of pericardial tamponade is likely an important survival determinant after cardiac SW but less important after cardiac GSW, its early detection is imperative.

The use of Focused Assessment with Sonography in Trauma (FAST) has greatly facilitated early detection of hemopericardium after penetrating injury. Subcostal and parasternal FAST ultrasound views have been reported to be both sensitive (96.8–100%) and specific (96.9–100%) for the detection of pericardial blood and cardiac injury after penetrating trauma.[50–54] One noteworthy limitation for the rapid adjunct is poor sensitivity (20%) for the detection of hemopericardium in the presence of associated hemothoraces.[55] The greater false-negative rate of ultrasound in this clinical scenario is likely related to the presence of a pericardial laceration which allows blood to decompress from the pericardial sac into the thoracic cavity. Although limitations of the technique are well-described, FAST does allow for the rapid detection of hemopericardium giving the bedside physician a better indication of the underlying anatomic injuries.

Primary anatomic injury location has been determined to influence survival after EDT. Reflecting the preponderance of stab wounds in earlier EDT series from prior decades, most authors would contend that patients with cardiac injuries have the best EDT survival rates. In their consensus statement, the American College of Surgeons Committee on Trauma concluded that ''EDT is best applied to patients sustaining penetrating cardiac injuries,'' but also may be performed on patients with non-cardiac thoracic injuries and patients with intra-abdominal hemorrhage.[45] The Rhee meta-analysis, comprising series from 2 to 4 decades ago, reported a 19.4% EDT survival rate in 1058 cardiac injured patients—a survival rate that likely reflects the successful resuscitation of patients with pericardial tamponade after cardiac stab wounds.[36] The same series reported a 10.7% survival rate in non-cardiac, thoracic injured patients and 4.5% survival after EDT for abdominal exsanguination. We recently reviewed 237 patients who underwent EDT for penetrating injury.[42] Of the 50 patients who underwent the resuscitative procedure for abdominal exsanguination, 16% survived, neurologically intact, until hospital discharge indicating that EDT is a useful tool in the surgeon's armamentarium when facing patients exsanguinating from abdominal haemorrhage.

Physiologic variables such as duration of cardiopulmonary arrest, the presence of field and ED signs of life, presenting cardiac rhythm, and the presence of vital signs are strongly related to injury mechanism and anatomic injury and all are important EDT survival determinants. In Powell's review of the Denver experience, 26 EDT survivors accrued over a 26-year period required prehospital CPR.[35] Importantly, each of these 26 survivors received less than 15 min of prehospital CPR and each of the 4 patients who survived prehospital CPR and EDT after blunt injury had poor neurologic outcomes. More recently, the Western Trauma group published their results from a 6-year observational study of EDT survivors at 18 trauma centres. Of the 34% of EDT survivors who required prehospital CPR, none survived EDT when preceded by >15 min of prehospital CPR.[46] In general, survival after 15 min of prehospital CPR is extremely uncommon, regardless of injury type, making rapid transport to a trauma centre essential for all salvageable patients.[14,43,46,56]

The role of pre-hospital personnel has expanded over the past 25 years to include performing procedures such as endotracheal intubation, IV line placement, and the administration of vasoactive medications. Although these therapies may benefit medical cardiac arrest victims, injured patients who are candidates for EDT seem best served by rapid transport to a trauma centre for definitive operative repair.[43,56–61] In 1982, Gervin and colleagues reviewed outcomes of 23 patients with penetrating cardiac wounds.[59] Half of the patients were transported promptly to the trauma centre with no in-field delays while the remaining patients were treated aggressively in the field with delays of 25 min or more. None of the patients resuscitated in the field survived but 80% survived when transport delays were minimised. Ivatury et al. compared survival rates of 51 patients with penetrating thoracic injury who had attempted stabilisation in the field to 49 patients with similar injuries who were transported immediately to a trauma centre.[56] Overall survival was significantly improved in the rapid transport group and they concluded that immediate transport without stabilisation in the field is the optimal prehospital management for these patients. In 2007, we published the results of a retrospective review of 180 patients requiring EDT. Of the 88 patients transported by EMS, 8% survived to hospital discharge while 17.4% of 92 patients transported by police or private vehicle survived to hospital discharge.[43] Through multivariate logistic regression analysis, we found that the performance of pre-hospital procedures (IV placement, endotracheal intubation, etc.) was an independent predictor of mortality. For each procedure performed, patients were 2.63 times more likely to die prior to hospital discharge. Overall, the current body of literature in America supports the rapid transport of critically injured patients who may require EDT or rapid definitive operative repair.[14,43,46,56–61]

Although *prehospital* thoracotomy is not currently practiced in the United States, reports from multiple European centres indicate that this intervention may offer a survival advantage to specific patients.[15,62,63] In 2000, Coats and colleagues published the results of a retrospective review of 39 pulseless, penetrating trauma victims who underwent pre-hospital thoracotomy, of which 4 (10%) survived.[62] Patients who were pulseless at the scene after penetrating injury with greater than 10 min of transport time to the nearest hospital underwent pre-hospital thoracotomy. Survival was associated with the following factors: stab wounds, cardiac tamponade, single cardiac wounds, and loss of pulse in the presence of an experienced physician. In 2006, Lockey et al. reviewed 909 patients requiring pre-hospital CPR, noting that 8 of the 68 survivors (11.8%) had a prehospital thoracotomy.[15] Most recently, Davies et al. performed a 15-year review of 71 patients with penetrating chest wounds who had pre-hospital thoracotomy.[63] Thirteen patients (18%) survived to hospital discharge. Although guidelines in the United States clearly indicate that thoracotomy is outside the remit of prehospital care, European hospital systems have utilised physicians in the prehospital phase for several years, facilitating the evolution of pre-hospital thoracotomy.

Upon patient arrival in the emergency department, the surgeon must rapidly assess for the presence or absence of signs of life, cardiac electrical rhythm, and vital signs. These physiologic variables are highly predictive of outcome after EDT. Although there is some debate in the trauma literature regarding the definition of a ‘‘sign of life,’’ many adhere to the expansive definition set forth by the American College of Surgeons Committee on Trauma.[45] A sign of life may be defined by any of the following physiologic parameters: pupillary response, spontaneous ventilation, the presence of a carotid pulse, measurable or palpable blood pressure, extremity movement, or any cardiac electrical activity.

Once again, FAST has become increasingly important, not only for the detection of pericardial tamponade and cardiac injury, but also for the determination of cardiac activity as well.[64–66] To our knowledge, only one report has analysed the role of FAST in determining cardiac activity of trauma patients. Schuster et al.[17] found that all survivors of traumatic PEA cardiopulmonary arrest had organised cardiac contractile activity on ultrasound. However, the utility of ultrasound in detecting either cardiac activity or a reversible cause of cardiopulmonary arrest in general cardiac arrest victims has been described and is likely applicable to injured patients also. Just as in general cardiac arrest victims, injured patients with sonographic evidence of asystole or PEA without a rapidly reversible cause (e.g. pericardial tamponade) are unlikely to survive despite any heroic attempts.[64–66] In the Joint Position Statement of the National Association of EMS Physicians and the American College of Surgeons Committee on Trauma,[14] another large review of all major studies regarding EDT was performed. Not surprisingly, patients who presented to the ED with signs of life, a sustainable cardiac rhythm, and obtainable vital signs fared better than patients with only the presence of signs of life. Both groups had greater survival than patients presenting without signs of life, a sustainable rhythm, or obtainable vital signs in the ED. In the Rhee analysis, patients arriving to the ED with evident signs of life experienced a 11.5% survival rate but only 2.6% of those without ED signs of life survived.[36] In contrast, reported survivors after EDT with absent field signs of life are virtually nonexistent in EDT literature. Thus, the use of EDT cannot be supported in this most critically injured subset of either blunt or penetrating-injured patients who lack signs of life at the scene, prior to hospital transfer.

Technical considerations and their scientific evidence

While the EDT procedure is relatively straightforward, several pitfalls must be avoided to optimise outcomes. The decision to perform an EDT must be made expeditiously once the injured patient arrives in extremis with all personnel in the trauma resuscitation area observing universal precautions. Patients with penetrating injuries are completely disrobed and quickly rolled in both directions to locate all wounds while the airway team assembles. As the patient is intubated and large-bore IV access is obtained, the bed is elevated to maximise exposure and the left arm is placed above the head of the patient. Skin is quickly prepped by pouring an iodine solution over both hemithoraces. Next, a generous incision is made with a number 10 blade from the right sternal border immediately below the nipple to the left posterior axillary line, angling slightly upward to following the anatomic curve of the rib. In thin patients, this incision should be made directly down to rib with the first scalpel pass. Next, the thoracic cavity is entered by making a small incision immediately above the exposed rib. The heavy, curved Mayo scissors are placed, partially opened, in the wound and ‘‘pushed’’ to the sternum. To complete the incision, the surgeon then turns his or her body and, with his back facing the patient, the Mayo scissors are pushed to the posterior axillary line. Now, with the thoracic cavity completely open, the Finichetto retractor is placed with arm of the retractor pointing towards the axilla to permit extension of the incision across the sternum for additional exposure if necessary. The retractor is widely opened for maximal exposure.

Once the thoracic cavity is opened, the exploration should proceed in a systematic fashion. First, the pericardium is opened by grasping the pericardium and making a small incision in the cranial to caudal direction, as far medial as possible to avoid injuring the lateral-lying phrenic nerves. The presence of hemopericardium is noted. The pericardiotomy is extended both cranially and caudally to expose the heart and great vessels. Importantly, the incision is not made in a right to left manner. After the incision is complete, the heart is then delivered from the pericardial sac and, by both visual inspection and manual palpation, the cardiac surface is explored for wounds.

Patients with cardiac injuries may be temporarily repaired until definitive operation. Temporising may be as simple as placing a finger on the wound while the patient is transported to the operating room, stapling the wound with a skin stapler (being careful to avoid coronary arteries), or suturing the wound with a monofilament, non-absorbable suture. Although suture repair is ideal, definitive repair is best accomplished in the operating room with adequate light, correct instruments and materials including pledgets, and a nursing and support staff who are accustomed to these procedures. Once the temporary repair of cardiac injuries is complete, exploration for other injuries ensues. In penetrating trauma victims, trajectories are followed looking for great vessel, lung parenchyma, chest wall, and diaphragmatic injuries. Major vascular injuries may be clamped or pressure applied to tamponade bleeding.

Open cardiac massage is then begun by placing the wrists of the caregiver together at the apex of the heart and squeezing the heart between two hands in a rhythmic clapping or ‘‘bellow-like’’ motion. Numerous reports have described the superiority of open chest cardiac massage over the traditional closed chest cardiac massage.[67–69,7,70] DeBehnke et al. utilised a canine myocardial infarction model with LAD occlusion and the induction of ventricular fibrillation.[68] After 8 min of closed chest CPR, animals were randomised to either open chest CPR, closed chest CPR, or cardiopulmonary bypass and concluded that open chest CPR resulted in improved coronary perfusion pressures when compared to closed chest CPR. The treatment benefit was observed in other canine studies which reported improved cardiac, cerebral, and carotid blood flow along with increased cerebral perfusion pressures. This effect was conserved among other animal species as well. In a prospective, randomised controlled trial utilising a porcine model randomised to open or closed chest cardiac massage, open chest massage provided better mean arterial pressures and twice the cardiac output as their closed chest counterparts.[70] Small human studies have also been reported. Boczar et al. reported 10 cardiac arrest patients who all underwent closed, followed by open chest cardiac massage.[67] Coronary perfusion pressures were 400% greater during open rather than closed chest cardiac massage. While external compressions provide approximately 25% of baseline cardiac output resulting in only 10% of normal cerebral and coronary flow, open cardiac massage after EDT is much more efficient, generating 60–70% of baseline cardiac output.[69,7] Closed chest compressions are especially ineffective in victims in haemorrhagic shock or pericardial tamponade. Furthermore, EDT with aortic cross-clamping redistributes the limited blood volume to the brain and myocardium and may limit haemorrhage from sub-diaphragmatic injuries.[20,71]

The next procedure in the systematic, complete EDT is the descending thoracic aortic cross-clamp occlusion. With the stretcher maximally elevated and overhead lights focused into the thoracic cavity, respirations are held for a moment while, with the left hand of the surgeon, the lung is retracted anteriorly and eviscerated. With the surgeon's right hand, a large Crawford clamp is applied to the thoracic descending aorta. To avoid any further bleeding, dissection above and below the aorta is best performed in a plane perpendicular to the aorta. Dissection should be at the level of an inter-vertebral space to avoid injury to intercostals vessels which branch from the aorta at mid-vertebral body. Importantly, the first objective during an exploratory laparotomy after thoracic aortic occlusion should be to slowly remove the thoracic cross-clamp, one ''click'' at a time, and replace the clamp below the renal arteries to reduce visceral ischaemia and reperfusion injury.

The effects of aortic occlusion have also been well described in various models.[20,71–76] Sankaran et al. induced intra-abdominal exsanguination by inserting a 3-mm metal rod through the canine aorta and infused saline into the abdomen of 5 animals.[74] The effects of thoracic aortic occlusion were analysed under various conditions and found to improve cardiac profiles in hypovolemic canine subjects without evidence of increased afterload or decreased contractility. Others have utilised transfemoral balloon aortic occlusion instead of thoracic aorta cross-clamping. Spence et al. prospectively evaluated 16 dogs that underwent open chest cardiac massage followed by open chest cardiac massage with balloon aortic occlusion.[75] The authors reported improved mean arterial pressures along with cerebral and cardiac perfusion during the aortic occlusion segment of the experiment. However, one report did highlight the potential hazards of thoracic aortic occlusion. In this study, 10 pigs were haemorrhaged and then randomised to aortic occlusion or no aortic occlusion groups.[71] The aortic occlusion group suffered increased left ventricular strain, reduced spinal cord flow, distal tissue ischaemia, increased oxygen debt, and increased metabolic acidosis. With the exception of EDT outcome and survival data from centres which practice this technique, the physiologic effects of temporary aortic cross clamping remain unstudied in humans.

Clinical data regarding pre-laparotomy EDT including open chest cardiac massage and thoracic aorta cross clamping for abdominal exsanguination is largely limited to EDT reports in which all injury locations including abdominal are described or abdominal vascular injury reports in which a portion of patients required EDT before laparotomy. In their landmark 1976 report, Ledgerwood, Kazmers, and Lucas brought 40 patients to the operating room for abdominal injury.[20] The majority of these patients suffered penetrating injuries (95%) causing haemorrhagic shock (80%). Twenty-nine had pre-laparotomy thoracotomy in the operating room of which 11 ultimately survived. Eleven patients had thoracotomies after laparotomy, 7 of which were due to sudden cardiovascular collapse upon opening the peritoneum. The authors concluded that left thoracotomy with aortic cross-clamping before laparotomy is a beneficial approach to the exsanguinating patient with abdominal injury. Similarly, Wiencek et al. retrospectively reviewed 154 patients with abdominal vascular injuries.[77] Forty-two of these patients had persistent shock of which 26 underwent pre-laparotomy thoracotomy in the OR and 5 (19.2%) survived. Only 1 of 17 (6%) of patients with persistent shock who underwent laparotomy without thoracotomy survived. More recently, we reported 16% of patients who underwent EDT for abdominal exsanguination after penetrating injury survived their hospitalisation.[42]

Lastly, coronary arteries should be inspected for the presence of air bubbles—a finding that is diagnostic for air embolism and therefore indicates an airspace to pulmonary vein fistulous tract. Several manoeuvres may be utilised if air embolism is encountered; a Duval clamp may be placed directly on the lung parenchyma to occlude the wound, the pulmonary hilum may be occluded with a large vascular clamp to prevent further air embolisation, or finally, the inferior pulmonary ligament may be completely mobilised from diaphragm to hilum and the lung ''spun'' on its hilum to occlude the vascular and airway structures.

The risks of EDT

Understanding the costs and risks associated with the indiscriminant performance of EDT, a more selective approach based on the presence or absence of the stated survival predictors has emerged. Several authors have reported that EDT is an inefficient use of police, EMS, and hospital resources, places personnel at undue risk for exposure to blood-borne pathogens, compromises human dignity, and salvages patients with permanent neurologic impairment.[9,11,25,27,33,35,38] While the costs of aggressively resuscitating nonsalvageable patients are substantial, attempts to quantify costs have been highly variable. Reported costs of the EDT procedure alone range from \$892 to \$7200[23,24,26,30,33,44] while costs per EDT survivor have ranged from \$13,674 to \$140,000,[21,27] likely reflecting differing patient populations, differing EDT practice patterns, and differing analytical methods.

More important than the costs of the procedure is the inherent risk to healthcare personnel. The prevalence of blood-borne pathogens such as HIV and hepatitis in the trauma population has been well-described. Since 1990, 8 published prospective reports have analysed the prevalence of HIV or hepatitis in trauma victims,[78–85] but only four of these 8 series[79,80,83,85] reported all relevant serum markers (anti-HIV, HBsAg, and anti-HCV). Of the 4 prospective reports that analysed all 3 bloodborne infections, one series described the prevalence rates specifically in penetrating injured patients—the subset of patients who most commonly undergo EDT at many urban trauma centres.[83] We found that the prevalence of HIV and hepatitis in our penetrating trauma population (HIV, 1.2%; HBsAg, 0.6%; HCV, 7.6%; 9.4% any infection) was similar to the aforementioned general trauma prevalence studies (HIV, 0–4.3%; HBsAg, 0.3–3.7%; HCV, 2.8–12.1%) but compared unfavourably to current CDC estimates (anti-HIV, 0.5%; HBsAg, 0.3%; anti-HCV, 1.3%) in the United States.[86,87] The risk to healthcare personnel is appreciable when the risk of transmission of these bloodborne diseases after occupational exposure is considered. While the risk of HIV infection after needlestick or cut exposure to HIV infected blood is relatively low (0.3%), hepatitis is much more readily transmissible through occupational exposure (HBV, 6–30%; HCV, 1.8% [range, 0–7%]).[88] In all cases, blood-borne pathogens are a significant concern and universal precautions must be maintained during all resuscitations.

Aside from costs and risk to healthcare personnel, EDT has been criticised for salvaging patients with anoxic brain injury and severe neurologic impairment. Several series have reported gross neurologic outcome data (impairment versus no impairment) along with long-term survival.[36,89] Rhee et al. reviewed these series to find 280 of 303 (92.4%) survivors of EDT to have a normal neurologic outcome in those that reported this outcome measure.[36] More recently the Western Trauma group reported that 18% of survivors in their multicentre, observational study had moderate to severe anoxic brain injury requiring placement in rehabilitation.[46] To our knowledge, no reports have described long term outcomes after hospital discharge following EDT.

We recently attempted to contact all 37 EDT survivors from the past 11 years at an urban, level I trauma centre (Seamon et al., unpublished data) to analyse their long term social, cognitive, functional, and psychological outcomes. Twenty-one patients or caregivers were contacted and invited to participate in an outpatient assessment and 16 EDT survivors completed the evaluation. Overall, 74% of hospital survivors had long-term social, cognitive, functional, or psychological impairment after EDT. Of these, alcohol and illicit drug use was common, 10% died after hospitalisation, 48% had impaired cognition and limited capacity to return to normal activity, 24% required assistance with activities of daily living, 13% were wheelchair dependent, 69% scored >1 standard deviation below national SF-36 means, and 25% had evidence of post traumatic stress disorder on initial screening measures. While survival is certainly possible after EDT, improved follow-up and long-term, multidisciplinary outpatient therapy will likely benefit survivors.

Conclusions

Level I evidence regarding the utilisation of CPR and EDT for traumatic arrest victims is nonexistent. Due to the nature of these critical injuries and the ethical concerns surrounding the randomisation of patients to a non-therapeutic control group, these study design limitations are unlikely to change. However, review of the existing literature reveals that certain patients clearly benefit more than others from these resuscitative interventions. Ultimately, the surgeon, armed with knowledge of these survival predictors, the risks associated with the resuscitation of critically injured patients, and sound clinical judgement, must decide when to terminate resuscitation for the unsalvageable or when to proceed with EDT in patients who have a chance of survival.

Conflict of interest statement

The authors declare that there is no conflict of interest.

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