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*Emergency department thoracotomy (EDT) is the most invasive and dramatic procedure that can be performed in the resuscitation of a trauma patient. The increased availability of rapid pre-hospital assessment and transportation of trauma patients has allowed patients who would never have survived in the past to be transported to the ED. ED physicians and trauma surgeons then are placed in the critical position of determining the etiology of the arrest, reversing any correctable processes, and deciding if an EDT is indicated. Lack of oxygen to the brain longer than 4-10 minutes does not bode a meaningful outcome. Therefore, the ED physician and trauma surgeon must have evidence-based information on indications for EDT that can be determined rapidly, easily accessible equipment, and the ability to recognize situations in which EDT clearly is not in the patient's best interest.*

*—The Editor*

## ED Thoracotomy Revisited: A Complete Reassessment of its Past, Present, and Future

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## Introduction

The EDT remains one of the most dramatic tools in the trauma surgeon's armamentarium. This technique has been practiced for years, although controversy has surrounded its use. As medicine has evolved, the indications for EDT have become more sophisticated. Settings where it has been used vary, and include penetrating thoracic and thoracoabdominal trauma.

The literature also reports its use in patients presenting in cardiopulmonary arrest secondary to isolated blunt trauma. Increasingly, medicine is required to answer many complicated questions regarding utility, ethics, and cost/risk-to-benefits ratios. Should we be performing a costly procedure that has a low rate of success? What is the benefit in saving a patient who survives with severe neurologic impairment, and what financial burden does that place on society?

Finally, does the diminutive survival benefit of such a procedure outweigh the potential for injury or transmission of disease to those performing and assisting in EDT? To completely understand the evolution of the EDT and improve our vision of its place in the future, it is necessary to identify the many historical events that shaped medicine and our world, making this procedure possible.

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## Historical Perspective

By the turn of the 20th century, America had established itself as a world power. The West was won. The frontier was no more. The continent was settled from coast to coast.

This was a time when J.P. Holland invented the first torpedo boat, elevating the United States Navy into a worldwide maritime force. King Camp Gillette developed the double-edged safety razor. The nation recovered from the assassination of its 25th president, William McKinley, and embraced Theodore Roosevelt as its new leader. Inventions revolutionized home travel, as well. Henry Ford introduced the Model T to the world, and the Wright brothers astonished us with the first powered, manned flight. With all that was going on in the world, medicine, too, was evolving.

In terms of chest surgery, four notable physicians demonstrated the feasibility of chest exploration for the treatment of injury. In 1874, Dr. Schiff first suggested open cardiac massage as a resuscitative measure for chloroform-induced cardiac arrest.[1] Then, in 1882, Dr. Block demonstrated the reality of opening the chest to repair cardiac injury in his canine experiments involving heart lacerations.[1-3] However, it wasn't until 1889 when the first successful open cardiac resuscitation was performed by Tuffier.[1] Dr. Rehn followed suit with the successful repair of a penetrating right ventricular injury in a human.[2,4] One year later, Dr. Ingelsrod successfully revived a post-injury cardiac arrest patient using open cardiac massage.[1] Claude Beck popularized open cardiac massage, and for the next 50-60 years, this became the standard of care for cardiac arrest in the operating room.[1,5] In 1947, he ultimately established the precedent of electrical defibrillation in the operating room and boasted a 29% survival rate for open cardiac massage on 1200 patients.[5] During the following years, exploration of the chest became a more common practice. Shortly thereafter, this practice fell out of vogue.[1]

Several key events gave rise the EDT's near elimination. In 1943, Drs. Alfred Blalock and Michael M. Ravitch (more well known for their contributions to pediatric surgery) perfected the technique of pericardiocentesis and advocated its use for the treatment of pericardial tamponade.[6] A decade later, Michael Zoll demonstrated the practicality of external defibrillation for life-threatening arrhythmias.[1,7] In the 1960s, Drs. Kownhoven, Jude, and Knickerbocker introduced closed-chest massage.[1] These new concepts and techniques shifted the medical tide away from the use of the EDT.

However, while history was staging itself for the near elimination of the EDT, other concepts in chest trauma were being discovered as a result of World War II. Heart-lung machines pioneered by Dr. John Gibbons allowed surgeons like Dr. Michael DeBakey of Baylor University in Houston to refine cardiothoracic techniques. Occlusion of the thoracic aorta now was possible in patients exsanguinating from abdominal trauma. Ultimately, this led to the revival of EDT.

## Rationale for Use of the ED Thoracotomy

With refined cardiothoracic techniques and the ability to cross-clamp the aorta, the EDT became more commonplace for patients in extremis with traumatic chest and/or abdominal injury. Since reversal of underlying causes of trauma arrest, which consists of hypovolemia, rapid hemorrhage or pericardial tamponade, is critical to patient survival, EDT is a valuable adjunct to a readily available surgical staff and definitive surgical repair. Guidelines were identified and more clearly defined to dictate the appropriateness of its use. The term "no signs of life," defined as no detectable blood pressure, papillary reactivity, respiratory effort, or cardiac electrical activity, clearly became a contraindication for EDT. However, physicians caring for patients with evidence of signs of life despite no vital signs still could make a valid argument for EDT.

Clearly, the decision to undertake such a formidable task should be based on scientific information directed toward

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The intended audience for this publication is emergency, family, osteopathic, and general practice physicians and nurses who have contact with trauma patients.

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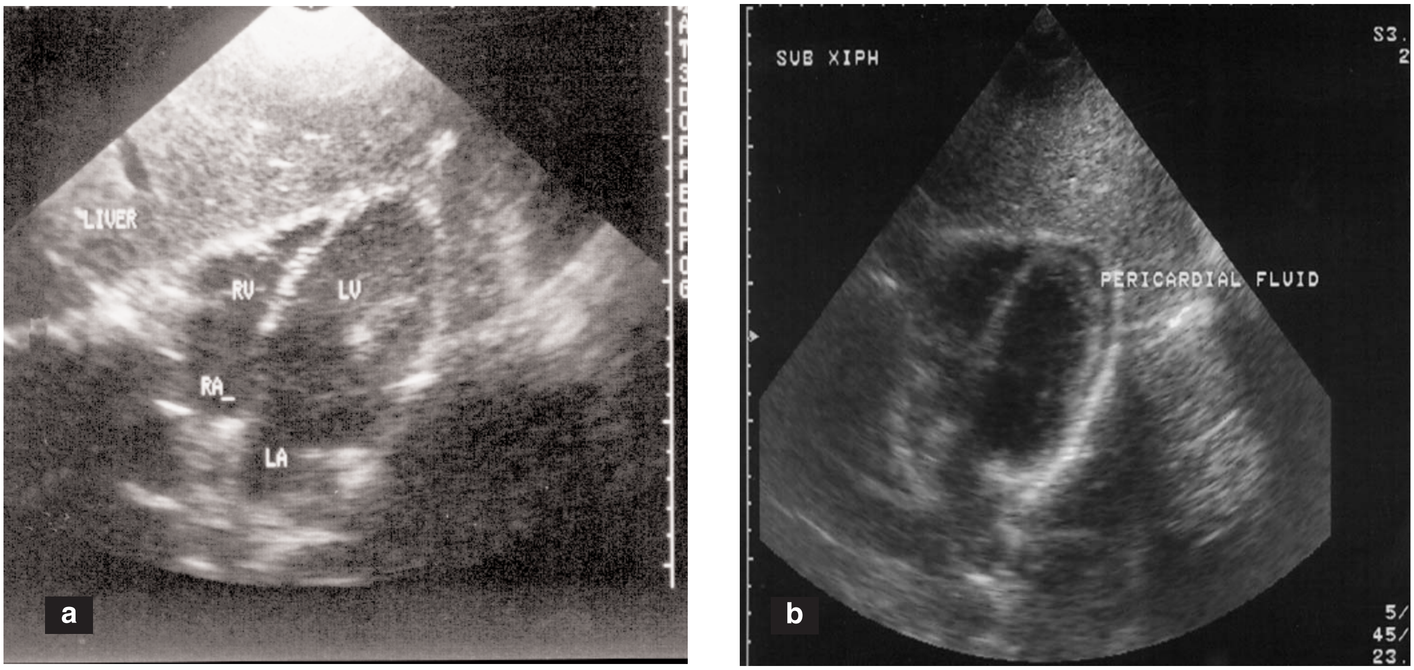
## Figures 1a and 1b. The Pericardial Window




1a. A normal pericardial window.
RV = right ventricle; LV = left ventricle; RA = right atrium; and LA = left atrium.

1b. Pericardial window that shows blood separating the visceral and parietal layers of the pericardium.

identifying and temporarily stabilizing specific correctible injuries. There are five basic motives for performing an EDT: 1) to release pericardial tamponade; 2) to control intra-thoracic vascular and/or cardiac bleeding; 3) to control massive air embolism or bronchopleural fistula; 4) to permit open cardiac massage; and 5) to provide temporary occlusion of the descending thoracic aorta to diminish intra-abdominal hemorrhage and optimize blood flow to the brain and heart.[1,3]

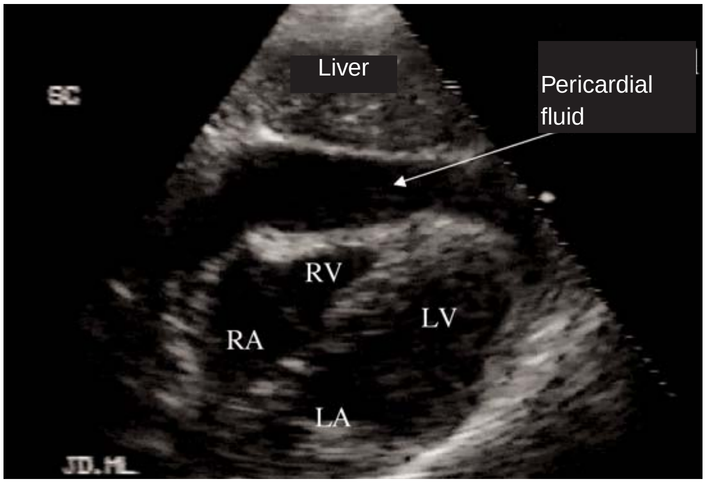
**Pericardial Tamponade.** Pericardial tamponade may result from gunshot wounds or stab wounds. Stab wounds commonly cause pericardial tamponade (80% of cases).[8] Pericardial tamponade can be characterized by Beck's triad (hypotension, distended neck veins, and muffled heart tones).[9] However, this triad has been demonstrated to have low specificity and sensitivity. More commonly, pericardial tamponade presents as a subtle constellation of symptoms with gradual progression of diminishing cardiac function. Often in trauma, the patient decompensates before the diagnosis is firmly established. Hence, it is important to understand the progressive three stages of pericardial tamponade that lead to death.

In stage one of traumatic pericardial tamponade, blood accumulates around the heart within the pericardial sac, resulting in increased pericardial pressures. *(See Figures 1a, 1b, and 2.)* This restricts ventricular diastolic filling and subendocardial blood flow. The body compensates for this by increasing heart rate, systemic vascular resistance, and central venous pressure. This represents an effective concerted effort of the body to maintain cardiac output. During this stage in traumatic pericardial tamponade, treatment consists of securing a patent airway, aggressive volume resuscitation, and pericardiocentesis.[6]

Stage two of traumatic pericardial tamponade results in further restriction of ventricular diastolic filling, stroke volume, and coronary perfusion from progressive increases in pericardial blood accumulation. Although blood pressure usually is maintained by the same stage-one compensatory mechanisms, clinical signs of shock begin to emerge. These signs may include anxiety, confusion, or unconsciousness; diaphoresis; pallor; diminished capillary refill and urinary output; tachycardia; and increased thirst. Strict control of the airway, aggressive volume resuscitation, and pericardiocentesis again are paramount in the treatment of this particular stage of traumatic pericardial tamponade. In addition, a sybxiphoid pericardial window made popular by Dr. J.K. Trinkle can be performed by the clinician to diagnose and treat pericardial tamponade.[6,9]

When the pericardial pressure approaches or exceeds the ventricular diastolic filling pressure, blood flow becomes ineffective. Failure of compensatory mechanisms results in global hypotension and severe coronary hypoperfusion. These events characterize this third and final stage of traumatic pericardial tamponade.[10] Without immediate treat-

**Figure 2. Subcostal Image of Traumatic Hemopericardium**




Key: RV= right ventricle; LV=left ventricle; RA=right atrium; LA=left atrium.
Image courtesy of Michael J. Lambert, MD.

**Table 1. Thoracotomy Equipment**

- Scalpel with #10 blade
- Mayo scissors
- Metzenbaum scissors
- Rib spreaders (Finichetto's)
- Lebsche's knife and mallet or Gigali's saw (for transecting sternum)
- Tooth forceps (2)
- Vascular clamps (2, Satinsky)
- Long needle holder (2, Hegan)
- 2.0 or larger silk strands
- 3.0 cardiovascular ethibond suture
- Suture scissors
- Aortic clamp (DeBakey or other)
- Tonsil clamps (4)
- Foley catheter (20 french, 30 mL balloon)
- Chest tube
- Towel clips
- Towels
- Laparotomy pads
- Teflon patches (different sizes)
- Internal fibrillation paddles

ment, cardiac arrest ensues. EDT is indicated to ensure the immediate evacuation of pericardial blood and to control the source of the bleeding.

**Intrathoracic Hemorrhage.** The presence of persistent intrathoracic bleeding is another reason to pursue an EDT. Intrathoracic bleeding can result from penetrating or blunt trauma. *(See Figures 3 and 4.)* The incidence of life-threatening intrathoracic bleeding, however, is less for blunt chest trauma compared to penetrating chest trauma (1-3% vs 3-5%) and usually is due to bleeding from the lung.[3,4,7,11-13] The highest salvage rates with cardiopulmonary resuscitation via EDT occur in patients who have sustained stab wounds to the heart and who go into cardiac arrest just before or soon after arrival to the ED.[3,4,7,11,13,14]

Because the chest is a large potential space, volume losses can be equally impressive and rapid. Each hemithorax can contain approximately 50% of the patient's blood volume (2.5 liters of blood for the average 70 kg person) before it becomes obvious.[3] Patients in extremis with isolated chest penetrating trauma should undergo an EDT to stop the bleeding.[3,7,11-14]

**Massive Air Embolism.** Air embolism in the setting of trauma is a subtle clinical finding and often is missed. Typically, patients have sustained penetrating chest trauma. After successful endotracheal intubation and positive-pressure ventilation, these patients usually develop precipitous shock. This results when air from the alveolovenous communication shower into the coronary arterial circulation. Myocardial hypoperfusion develops, followed by rapid and global myocardial ischemia. If an EDT is not judiciously performed, cardiac arrest ensues. The goal of the EDT is to cross-clamp the pulmonary hilum on the side of injury to prevent more air from entering the vascular tree. The air should be vented from the ventricles and aorta with the patient in the Trendelenburg position.[15]

**Open Cardiac Massage.** Open cardiac massage first was proposed by Dr. Schiff in 1874.[1,13] Almost 100 years later, Drs. Kownhoven, Jude, and Knickerbocker introduced closed-chest massage.[1] Since then, both techniques have been scrutinized. There is scientific data to support the rationale of use of both techniques. Overall, open cardiac massage has been shown to be superior to closed-chest compressions.[16] *(See Figure 5.)* Properly performed external cardiac compression can provide up to 10-20% of baseline cardiac output, 3-10% of cerebral perfusion, and 3-10% of coronary perfusion.[17] This allows for reasonable salvage only up to15 minutes, with diminishing survival rates at 30 minutes of cardiopulmonary resuscitation.[16,17] This data pales in comparison to that generated from open cardiac massage in euvolemic patients. Open cardiac massage can deliver up to 60% of baseline (pre-arrest) aortic pressures and cardiac outputs often can be maintained at 50-70% of baseline. This allows for adequate cerebral and coronary perfusion, and hence, reasonable salvage at 30 minutes.[5,17] Because of these studies, there has been increasing discussion about returning to open cardiac massage for resuscitation.

The trauma population is unique in that the hypovolemic patient is more prevalent than in the general medical population. In 1989, Luna and associates demonstrated that external cardiac compressions in the face of hypovolemia and reduced ventricular filling provided inadequate coronary and cerebral perfusion.[15] Animal research clearly demonstrates a marked hemodynamic improvement with open cardiac massage vs. closed-chest compressions (especially beyond two

**Figure 3. Penetrating Wound to the Chest**


Patient who sustained a penetrating wound to the chest.

minutes).[5] Finally, direct intra-arterial pressure monitoring during external compressions in patients has consistently demonstrated that the maximal aortic pressures generated during precordial compression correlate poorly with cardiac output.[5] These studies solidify the argument for open cardiac massage over closed-chest compressions.

**Intra-abdominal Hemorrhage.** Performance of EDT for patients with intra-abdominal exsanguinations has been under much debate. Occluding the thoracic aorta could prevent further volume losses below the diaphragm and redistribute blood flow to organs of highest priority—namely, the brain and the myocardium. Studies have shown that clamping the thoracic aorta doubles the mean arterial pressure and cardiac output during hypovolemic shock, allowing these organs to be adequately perfused. However, providing adequate blood flow to these organs comes at a steep price. In the euvolemic patient, this maneuver increases afterload (systemic vascular resistance) and, thus, the oxygen demands placed on the myocardium. It also reduces blood flow by 90% to the abdominal viscera, the spinal cord, and the kidneys. Cross-clamp times up to 30 minutes in elective cases have been well-tolerated. Beyond this time, significant ischemia is encountered. Anaerobic metabolism gives rise to acidemia, which potentiates the typical cascade of events intimately linked to multiple organ dysfunction. Although the idea of temporary aortic clamping to reduce intra-abdominal blood losses and redistribute blood flow to vital organs is sound, there is little current data to suggest that it significantly improves the patient's overall survival rate.[10,18,19]

## Technical Aspects of the ED Thoracotomy

**Preparation.** Before performing an EDT, it is necessary to ensure preparedness. A staff skilled in performing an EDT and providing post-EDT resuscitation is a necessity.[20] An EDT tray should be available at all times. This tray should include a scalpel with a No. 10 blade, curved Mayo's and Metzenbaum's scissors, a Finichetto's chest retractor, a Lebsche's knife and mallet or Gigali's saw, long Debakey's vascular forceps, a Satinksky's vascular clamp, Debakey's aortic clamp, a needle driver, non-absorbable suture, pledgets, a Foley balloon, silk ties, sterile towels, and laparotomy pads. The staff should be familiar with the contents of this tray and should observe universal precautions during the procedure. *(See Table 1.)*

**The Procedure.** As with all surgical procedures, the approach to the EDT should be very systematic. The stepwise approach consists of exposure, pericardiotomy, repair of cardiac injury, open cardiac massage, aortic occlusion, and pulmonary hilar cross clamping (if necessary). Definitive management should be accomplished in the operative theater with optimal lighting, equipment, and sterility.

The left anterolateral thoracotomy incision is the pre-

**Figure 4. Isolated Stab Wound to the Chest**

This male received an isolated stab wound to his chest.

ferred approach for open cardiac massage. This incision can be extended across the sternum into the right chest to provide exposure of both pleural spaces and virtually all mediastinal structures. *(See Figure 6.)* It is initiated by a swift incision at the level of the fourth to fifth intercostal space (in most cases). A right-sided thoracotomy is reserved for the hypotensive patient with an isolated right-sided penetrating injury. Partial division of the overlying perctoralis and serratus muscles help in exposing the fifth intercostal space. The intercostal muscles and parietal pleura are then divided with heavy curved Mayo's scissors along the superior rib edge so as not to injure the inferiorly positioned intercostal neurovascular bundle. The Finichetto's rib retractor is placed with the handle positioned posteriorly to prevent repositioning if a trans-sternal incision is required. This can be done with a Lebsche's knife and mallet or a Gigali's saw. Be aware that the internal mammary vessels lie approximately 0.5-1 cm lateral to the lateral margin of the sternum. Care must be given to identifying these vascular structures and tying them off. Inadvertently lacerating these vessels can lead to significant blood loss and consume valuable time needed for definitive therapy.

Once adequate exposure is established, the pericardial sac should be opened longitudinally on the anterior surface so as not to injure the pericardiacophrenic complex.

The tense pericardial sac may be difficult to grasp and cut with scissors. It is best to make a small nick in the pericardium with a knife, then carefully extend the pericardiotomy with scissors. The pericardiotomy should extend along the ascending aorta to the top of the pericardium and inferiorly to the level of the diaphragm. This will provide maximum exposure and prevent cardiac strangulation. Blood clots should be evacuated rapidly from the pericardium. In the event of cardiac arrest, bimanual open cardiac massage should be initiated as described by Moore, et al.[18,21] This is done with the palms of the hands hinged together and the fingers providing compression of the ventricles from the apex to the base of the heart. The pads of the fingers never should be used to provide cardiac compression. This technique minimizes the risk of myocardial perforation. If the sternum is intact, open cardiac massage alternatively can be performed by compressing the heart up against the sternum.

Bleeding sites from the heart usually are controlled with light digital pressure. The suturing should be done rapidly with 3-0 non-absorbable sutures prior to defibrillation. Partially occluding clamps can be used to control bleeding from the atrium or great vessels. Ventricular exsanguination can be controlled by inserting a Foley catheter into the ventricular defect. The balloon is inflated, and the catheter is bolstered in place with a non-absorbable purse-string suture. The Foley catheter also can be used for intra-cardiac high volume resuscitation. Definitive repair of ventricular wounds should be performed in the operative theater with 2-0 non-absorbable horizontal mattress sutures buttressed with Teflon pledgets. Posterior cardiac wounds are very treacherous due to limited exposure. Attempts at repair must be made only in the operative theater with optimal lighting and equipment. These injuries usually are associated with a very high mortality rate. Cardiopulmonary bypass should be considered early if there is massive bleeding and/or cardiac irritability every time the heart is lifted to view or repair the posterior injury.

If the heart is void of gross injury and open cardiac massage and/or internal defibrillation do not restore vigorous cardiac activity, the descending thoracic aorta should be occluded inferior to the left pulmonary hilum. It is not necessary to encircle the aorta with the Satinsky's or Debakey's vascular clamp. The aorta can be dissected away from the esophagus anteriorly by incising the mediastinal pleura and away from the prevertebral fascia posteriorly. Encircling the aorta only will increase the likelihood of esophageal injury.

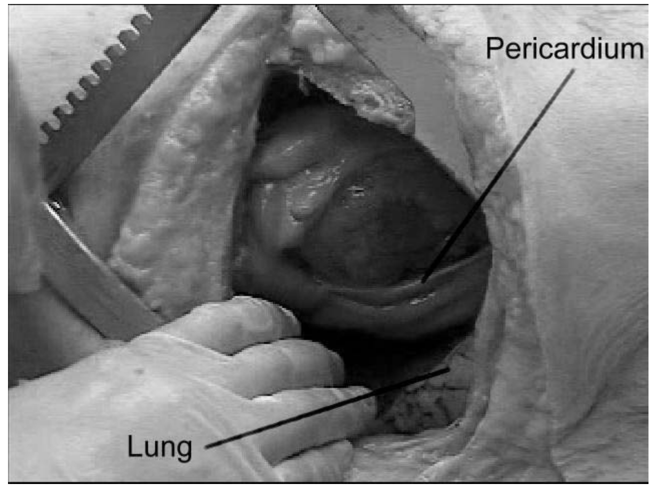
After occlusion of the aorta and aggressive fluid resuscitation the blood pressures should be monitored closely as this provides important prognostic information. If the systolic blood pressure remains below 70 mmHg, it is unlikely that the patient will survive.[12,13,15,16,22,23] On the other hand, if the systolic blood pressure exceeds 160-180 mmHg, the resultant strain on the left ventricle can lead to acute left ventricular distension/failure and pulmonary edema. The clamp should be removed as soon as an effective systemic arterial pressure has been achieved. When aortic cross clamp times exceed 30 minutes, the metabolic penalty becomes exponential. This especially is true in multisystem trauma.

If coronary or systemic air emboli are present, the pulmonary hilum should be clamped to prevent further embolism. Retracting the lung inferiorly can provide adequate exposure of the pulmonary hilum for clamping from a superior to inferior approach. Air can then be aspirated from the apex of the ventricle and the aorta with the patient in a Trendelenburg position.

**Figure 5. Cardiac Massage**

Used with permission from: ED thoracotomy. Trauma.org, June 2001. WWW.trauma.org/thoracic/EDToperative.html (Accessed 10/8/2003.)

**Figure 6. EDT Landmarks**

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A systematic approach to the EDT should be honored every time this procedure is performed. Adherence to these basic steps will minimize delays in diagnosis/repair and minimize injury to self and the trauma team.

**The Aftermath.** If spontaneous cardiac function resumes, the resuscitation priorities shift to maximizing oxygen delivery to the injured tissues. The after-affects of EDT usually results in direct cardiac injury, myocardial ischemia, circulation of cardiac depressants, pulmonary hypertension, and reperfusion injury.[10] Declamping the aorta causes a washout of metabolic by-products and inflammatory mediators into the systemic circulation that may initiate a cascade of events resulting in shock and triggering the systemic inflammatory response. Thus, it becomes paramount to address issues of non-delivery dependent oxygen consumption ($VO_2$). This is accomplished by raising oxygen delivery ($DO_2$) until oxygen consumption is supranormal and/or will not rise further with increases in $DO_2$.

Oxygen delivery is a function of the cardiac output and the oxygen concentration of blood (oxygen carrying capacity). Cardiac output (CO) is related to stroke volume and heart rate. The oxygen concentration of blood is largely related to the hemoglobin concentration (Hgb) and oxygen saturation ($SaO_2$). To optimize $DO_2$, the circulating blood volume should be increased until the cardiac index is 4-405 L/min/$m^2$ or until the cardiac output will not increase with further elevation of end diastolic volume (EDV). The oxygen concentration of blood can be maximized by increasing the hematocrit levels above 35-40%. Fleming and colleagues clearly have demonstrated that if these strategies fail to increase $VO_2$ to at least 150 cc/min/$m^2$ within 12 hours of injury, there is an increased incidence of multiple organ failure. In addition, they demonstrated that using supranormal CI, $DO_2$, and $VO_2$ parameters can decrease mortality from 50% to 20%.

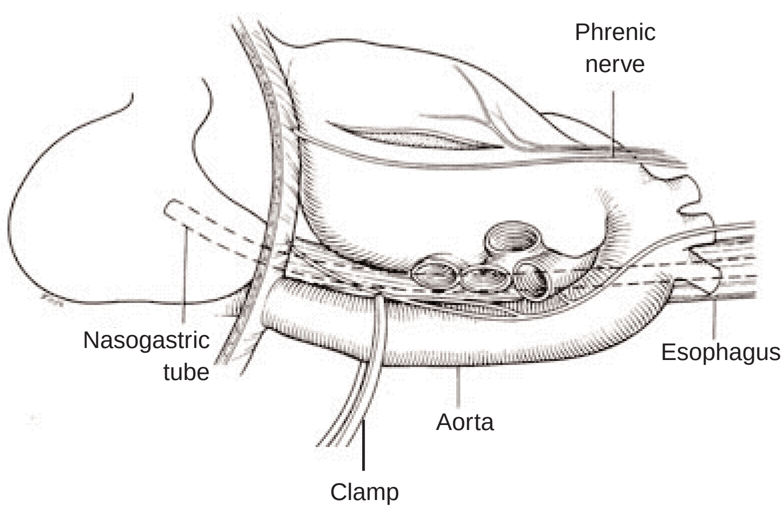
## Complications

The EDT can be fraught with hazards in every step of the procedure. Technical complications may involve virtually every intrathoracic structure. Reported complications include injury of the heart, coronary arteries, aorta, intercostals arteries, phrenic nerves, esophagus, and lungs.[21] Adhesions from previous thoracotomies can make performing an EDT extremely challenging and represents a relative contraindication to EDT. Nonetheless, a midline sternotomy for cardiac injuries still remains a viable option for safe exposure.

Other very important, often overlooked and undermentioned complications include accidental injury or disease transmission to the surgeon, assistant and trauma team. Oftentimes, the initial trauma assessment can be chaotic and confusing. This is the perfect environment for injury and blood borne disease transmission. In this setting, it is necessary to regroup thoughts prior to making the initial skin incision and proceed swiftly, safely, and systematically with caution.

For those patients who survive EDT, the most common postoperative complications include atelectasis, pneumonia, recurrent bleeding, diffuse intravascular coagulation, empyema, infections, and sternal dehiscence.[21] The management of these individual problems will not be discussed, as this is beyond the scope of this paper.

**Figure 7. Cross-clamp of the Aorta**

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## Current Guidelines for the Use of ED Thoracotomy

In mid-1999, the American College of Surgeons—Committee on Trauma employed a Working Group, Ad Hoc Subcommittee on Outcomes to embark on the monumental task of reevaluating the use of the EDT. The five questions that they set out to answer included: 1) Which patients should be subjected to EDT? 2) What are the valuable physiologic predictors of favorable outcomes? 3) What is the true survival rate of this procedure? 4) How may survivors succumb to severe neurologic impairment? 5) How can we ensure that those performing EDT are qualified?[22,24]

Literature from 1966 to 1999 was meticulously reviewed and separated based on data classification. There were no Class I (prospective randomized controlled) trials identified. There were 29 Class II (clearly reliable data collected prospectively and retrospectively analyzed) and 63 Class III (retrospectively collected data) studies identified.[21-28]

**Which patients should be subjected to EDT?** In April 2001, the ACS-COT Subcommittee on Outcomes gave their final recommendations regarding EDT.[24,26] *(See Table 2.)* As expected there was insufficient evidence to support a Level I recommendation for this practice guideline. Their Level II recommendations are as follows:

- EDTs should be performed rarely in patients sustaining cardiopulmonary arrest secondary to blunt trauma due to the unacceptably low survival rate and poor neurologic outcomes;[22]
- EDT should be limited to those that arrive with vital signs at the trauma center and experience a witnessed cardiopulmonary arrest;[16]
- EDT is best applied to patients sustaining penetrating cardiac injuries who arrive at trauma centers after a short scene and transport time with witnessed signs of life;[12,13]
- EDT should be performed in patients sustaining penetrating non-cardiac thoracic injuries.[12,13,15,16,22,23] They did acknowledge the difficulty in ascertaining whether the thoracic injury was cardiac or non-cardiac and promoted the use of EDT to establish the diagnosis; and
- EDT should be performed in patients sustaining exsanguinating abdominal vascular injuries although these patients experience a low survival rate.

The above Level II recommendations also are applicable to the pediatric trauma population.

**What is the true survival rate of this procedure?** Of studies reporting EDT, 7035 procedures were performed with a survival rate of 7.83%. These procedures were stratified by the mechanism of injury. The survival rate for EDT based on penetrating trauma was 11.16%. The survival rate for EDT based on blunt trauma was 1.6%. The survival rate for EDT based on penetrating cardiac injury was 31.1%[22,25,26,29]

Four series included pediatric trauma patients. The overall survival rate for 142 patients who required an EDT was 6.3%. When stratified by the mechanism of injury, the survival rate for penetrating trauma was 12.2% vs. 2.3% for blunt trauma. There was no reliable data reporting penetrating cardiac injuries in the pediatric population.

**How may survivors succumb to severe neurologic impairment?** Of the series reporting neurologic outcomes, 4520 patients were subjected to EDT. There was a 5% overall survival rate. Of these survivors, 15% survived with severe neurologic impairment.

**What are the valuable physiologic predictors of favorable outcomes?** Physiologic predictors of outcomes for EDT have been identified. In 1983, Cogbill and associates determined four statistically significant indicators that portend a dismal outcome. They are: 1) no signs of life at the scene; 2) no signs of life in the ED; 3) no cardiac activity at the time of EDT; and 4) persistent hypotension (SBP < 70 mmHg) despite aortic occlusion. Five years later, Branney and his group determined that the absence of vital signs in the face of blunt trauma also led to a poor outcome.[22,25,26,29]

**How can we ensure that those performing EDT are qualified?** Although reports of a successful roadside resuscitative thoracotomy in a man sustaining a stab wound to the left lower lobe of the lung has been published by Wall et al,[20] enthusiasm for the use of EDT should be tempered by the receiving hospital's ED resources and the surgical experience of their physicians. Currently, a certification course for EDT does not exist. The technical aspects of EDT is taught at the level of surgical residency. There is much debate regarding the qualification of emergency medicine

**Table 2. ACS-COT Subcommittee on Outcomes: Recommendations on EDT**

- EDTs should be performed rarely in patients sustaining cardiopulmonary arrest secondary to blunt trauma due to the unacceptably low survival rate and poor neurologic outcomes.
- EDT should be limited to those that arrive with vital signs at the trauma center and experience a witnessed cardiopulmonary arrest.
- EDT is best applied to patients sustaining penetrating cardiac injuries who arrive at a trauma center after a short scene and transport time with witnessed signs of life.
- EDT should be performed in patients sustaining penetrating non-cardiac thoracic injuries.
- EDT should be performed in patients sustaining exsanguinating abdominal vascular injuries although these patients experience a low survival rate.

(The above Level II recommendations also are applicable to the pediatric trauma population.)

physicians to perform this procedure. The optimal benefit of the EDT is achieved at a trauma center by a trauma-trained surgeon or surgeon experienced in the management of major intrathoracic injuries. The emergency medicine physician should not hesitate to perform an EDT, provided that a trauma-trained surgeon is available readily to deliver definitive surgical care. Provision for emergency medicine physicians to perform EDT to temporize problems without the immediate availability of the surgeon is, quite honestly, a waste of time and resources and a significant risk of injury/disease to the trauma team. Be that as it may, the prerequisites for performing EDT should include: 1) a physician experienced in performing thoracotomies and open cardiac massage; and 2) an ED/surgery system that rapidly can provide surgical support.

## Conclusions

Chest surgery for open cardiac massage and the repair of injury was first demonstrated at the turn of the 20th century—a time of American ingenuity and innovation in modern medicine. The EDT as a technique for resuscitation of moribund thoracic trauma patients became popular in the 1960s. Enthusiasm for this procedure subsequently led to the employment of EDT in the setting of extrathoracic penetrating trauma and blunt trauma. However, interest in EDT for blunt trauma waned as data (largely retrospective) accumulated demonstrating minimal survival benefit from this procedure.

The rationale for use of EDT includes the release of pericardial tamponade, control of intrathoracic bleeding, control of massive air embolism, open cardiac massage, and temporary occlusion of the descending thoracic aorta to diminish intra-abdominal hemorrhage and optimize blood flow to the brain and the heart. Following successful EDT, the primary goal of resuscitation then focuses on maximizing oxygen delivery to tissues that have been deprived and injured. This is done by optimizing cardiac function and oxygen-carrying capacity at supranormal levels. Evidence exists to validate the utility of these goals, and the newer pulmonary artery catheters can assist in achieving these endpoints.

The literature is replete with data regarding all controversies and questions surrounding this formidable procedure. The issues that have been raised include EDT candidates, survival determinants of patients undergoing EDT for blunt vs. penetrating trauma, the neurologic sequelae of EDT, and quality issues of those performing this procedure. In one of the most complete recent assessments of EDT by the American College of Surgeons Committee on Trauma, these issues were addressed. The committee identified 167,735 studies from trauma centers across the nation, and conducted a strict selection process that narrowed the number of studies to 92. Those studies were then classified according to the scientific evidence and formulation of recommendations scheme. Ultimately, the ACS-COT practice management guidelines recommended EDT's best utility is in those patients sustaining penetrating non-cardiac injuries and exsanguinating abdominal vascular injuries. These same recommendations held true for both the adult and pediatric trauma population.

As medicine faces further scrutiny by the public regarding suitable appropriation of limited resources, it becomes even more critical to identify which patients face mortality and/or severe neurologic impairment. The future will focus on defining nonsalvageability early in the resuscitative effort. Currently, work is underway to identify markers of brain metabolic activity that may assist physicians in earlier termination of futile efforts prior to the consumption of our valuable limited resources.

Other current areas of focus strive to attenuate reperfusion injury, limit the generation of oxidant metabolites during reperfusion, decrease the elaboration of harmful cytokines produced by endothelial cells and macrophages during tissue injury, and pacify primed neutrophils that play a vital role in the inflammatory cascade. The new millennium brings exciting innovations and possibilities in reference to trauma resuscitation. It will be exciting to witness how these discoveries will change the face of our current decision algorithm for the selective use of resuscitative thoracotomy in the ED.

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## CE/CME Questions

1. Which of the following is a situation in which EDT may be beneficial to the patient?
   A. Release pericardial tamponade.
   B. Control intrathoracic vascular /or cardiac bleeding.
   C. Control massive air embolism.
   D. Permit open cardiac massage.
   E. All of the above

2. The incidence of life-threatening intrathoracic bleeding is less for blunt chest trauma compared to penetrating chest trauma.
   A. True
   B. False

## CME Objectives

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

a.) Quickly recognize or increase index of suspicion for traumatic injuries that may require ED thoracotomy;

b.) Be educated about how to correctly and quickly perform an EDT;

c.) Understand situations where an EDT will not be beneficial; and

d.) Understand both likely and rare complications that may occur.

## CE/CME Instructions

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 <u>must</u> complete the evaluation form provided and return it in the reply envelope provided in order to receive a certificate of completion.** When your evaluation is received, a certificate will be mailed to you.

3. The highest salvage rates for EDT occur in patients with stab wounds to the heart who go into cardiac arrest just before or soon after arrival in the ED.
   A. True
   B. False

4. Which of the following is true regarding air embolism?
   A. Air embolism, in the setting of trauma, is usually very obvious.
   B. Typically the patient has sustained blunt trauma.
   C. Following intubation and positive pressure ventilation, patients with this disease develop precipitous shock.
   D. Shock results from blood loss into the pericardium.

5. Overall, open cardiac massage has been shown to be superior to closed chest compressions.
   A. True
   B. False

6. Which of the following are prerequisites to performing an EDT?
   A. Skilled staff
   B. Easy availability of an appropriately equipped EDT tray
   C. Familiarity with the tray and the procedure
   D. Use of universal precautions
   E. All of the above

7. The left anterolateral thoracotomy incision is the preferred approach for open cardiac massage.
   A. True
   B. False

8. Which of the following are possible complications of an EDT?
   A. Cardiac injury
   B. Atelectasis
   C. Pneumonia
   D. Infection
   E. All of the above

9. EDT should be performed in all patients sustaining cardiopulmonary arrest secondary to blunt trauma.
   A. True
   B. False

10. EDT is best applied to patients sustaining penetrating cardiac injuries who arrive at trauma centers after a short scene and transport time with witnessed signs of life.
   A. True
   B. False

## Answer Key

| | |
|---|---|
| 1. E | 6. E |
| 2. A | 7. A |
| 3. A | 8. E |
| 4. C | 9. B |
| 5. A | 10. A |



**In Future Issues:**

**Delayed Diagnoses**