

Resuscitative Thoracotomy

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In the United States trauma is the leading cause of death in people aged 1 through 44.¹ Blunt trauma accounts for the majority of trauma mortality overall, but in urban settings penetrating trauma, including firearm-related injuries, accounts

for an increased proportion of trauma deaths. In 2013, more than 33,000 firearm-related deaths occurred in the United States,² with many victims arriving at the emergency department (ED) in extremis.

Severe traumatic injuries can be associated with a very high mortality rate. However, on rare occasions an aggressive approach involving the use of emergency department thoracotomy (EDT) leads to survival in patients with impending or recent traumatic arrest. EDT is a dramatic, heroic intervention performed outside the operating room and often in the absence of trained cardiothoracic or trauma surgeons. Though supported as a potential lifesaving procedure, EDT is not a mandated standard of care nor a procedure that is expected

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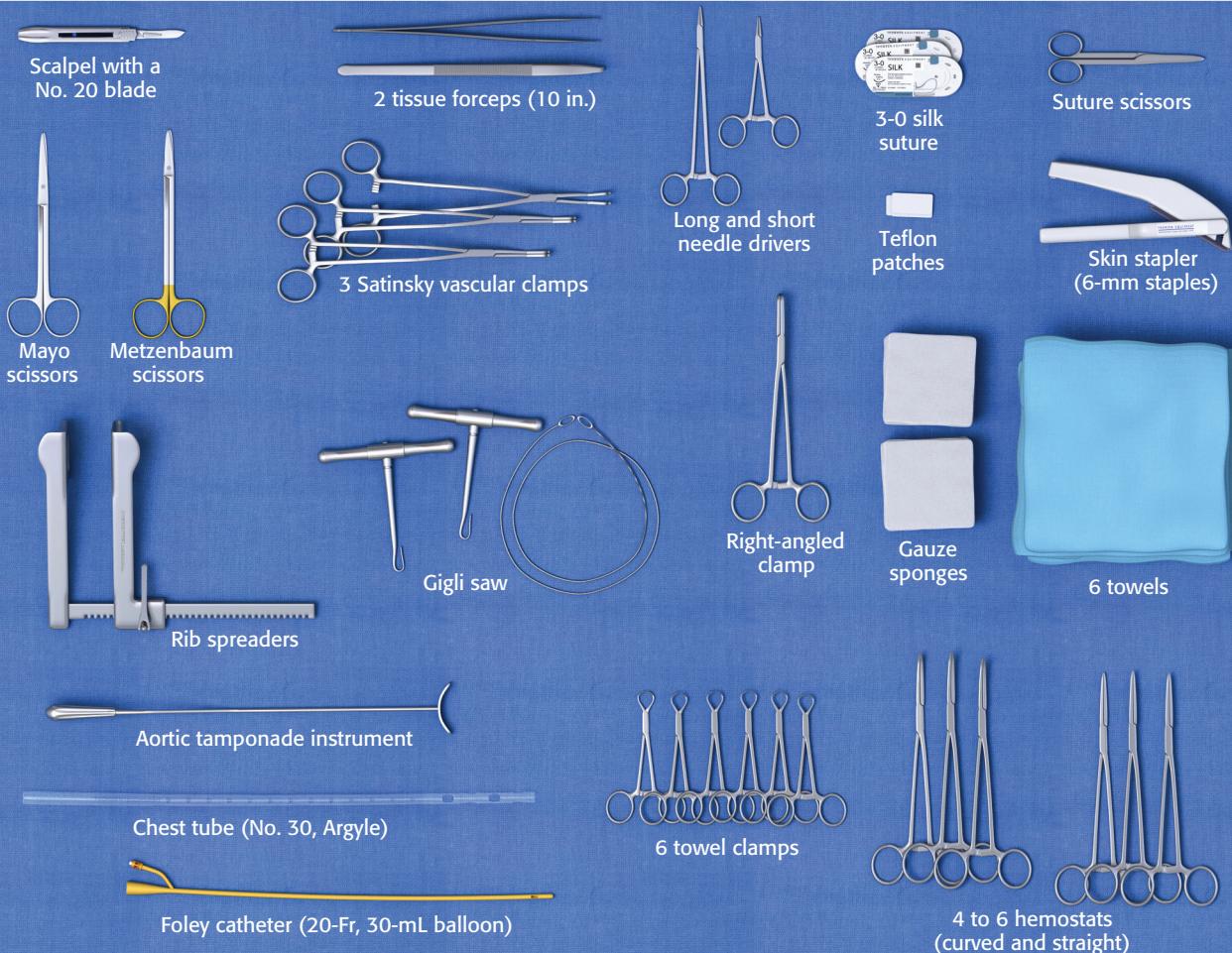
Indications

Trauma victims with severe refractory instability or cardiac arrest
Nontraumatic hypothermic cardiac arrest

Contraindications

Blunt trauma cardiac arrest patients without signs of life
Trauma patients with obvious non-survivable injuries
Initial rhythm of asystole without signs of life
Signs of prolonged arrest including lividity or rigor

Equipment



Review Box 18.1 Resuscitative thoracotomy: indications, contraindications, equipment, and complications.

to be performed in most EDs. The first successful thoracotomy was reported more than 100 years ago, and the first EDT was reported in 1966.³ Since then, multiple studies have reported outcomes, indications, techniques, and risks associated with the procedure. In 2003, the National Association of EMS Physicians Standards and Clinical Practice Committee and the American College of Surgeons Committee on Trauma (ACSCOT) proposed specific guidelines for EDT.⁴ Several other guidelines have been published without consensus guidelines on the ideal candidates for EDT.^{5,6}

Given the circumstances surrounding the procedure and the associated injuries, few patients survive. The poor overall survival rates, however, should not discourage performance of the procedure in the correct setting and when appropriate surgical backup is available for definitive care.

EDT is not a simple procedure (Video 18.1). Identifying specific structures within a chest cavity filled with blood, coupled with a collapsed lung and an injured heart and major vessels, can be formidable. Localizing the injuries that can be reversed quickly and safely is even more difficult.

This chapter focuses on three major objectives: (1) identifying possible indications for and contraindications to EDT, (2) describing the technical aspects of the procedure and adjunctive maneuvers to repair specific injuries, and (3) recognizing the associated risks and complications.

Because of the controversies surrounding EDT, every institution should have guidelines for its appropriate use. An institutional plan for chest wound management and postprocedural care should also be established with the service that will provide backup when members of the surgical team cannot be on site at the time of resuscitation. Debate regarding who should perform EDT is not necessary because everyone who is licensed to perform resuscitative thoracotomy should be trained, competent, and prepared for the technical and initial critical care aspects of patient management. Patient care needs in the event of successful resuscitation should be considered in advance and the surgical and intensive care teams notified so that they can mobilize the appropriate supplies, equipment, and personnel.

INDICATIONS AND CONTRAINDICATIONS

In the ED the vast majority of thoracotomies are performed on penetrating trauma patients in cardiac arrest. Beall and coworkers initially proposed EDT for the treatment of penetrating cardiac injuries in 1966.³ Since then it has been expanded to include extrathoracic injuries, blunt trauma, and nontraumatic pathology. Studies show wide variation in survival rates and outcomes. Taking 50 years of collective EDT data into account, the survival rate of patients undergoing EDT for blunt trauma is nearly 2%, whereas that for penetrating trauma is nearly 10%,⁵ but these survival rates depend on many variables and are not applicable to every situation. There is a paucity of data concerning survival rates in patients with EDT performed for nontraumatic causes, and it is not recommended that this procedure be regularly used in these settings.

Make the decision to perform EDT quickly based on whether the patient is likely to benefit from the procedure, has a reasonable chance of survival, and cannot tolerate a delay in operative intervention. In addition, consider the risks associated with performing the procedure. Trauma researchers have identified

BOX 18.1 Factors Used to Determine Which Patients May Benefit From EDT

- Mechanism of injury
- Location of injury
- Initial cardiac rhythm
- Resuscitation (cardiopulmonary) time
- Signs of life

several factors that are considered crucial when determining who will benefit from EDT (Box 18.1).

The first assessment is made in the prehospital setting, where determination of the mechanism of injury and the presence or absence of a pulse is critical. Multiple guidelines recommend against EDT in patients without a pulse, blunt traumatic mechanisms, and without signs of life.⁴⁻⁶ Such patients do not survive, regardless of the intervention. In one of the largest EDT series to date, Branney and coworkers⁷ reviewed 868 consecutive patients over a 23-year period. They found that no blunt trauma patients survived EDT when they had no vital signs in the field, but that 2.5% of blunt trauma patients survived EDT when vital signs were present in the field. In 2000 Rhee and colleagues⁸ examined 4620 cases of EDT from 24 studies over a 25-year period. The overall survival rate after blunt trauma was just 1.4%, which led to EDT falling out of favor for this indication. Recent articles have challenged the idea of limiting EDT to those in cardiac arrest from penetrating injury only.^{5,6,9-11}

The survival rate of pulseless trauma patients sustaining penetrating injury is significantly higher than that of blunt trauma patients. Several penetrating injury subtypes have been studied as follows: firearm injuries, stab wounds, and penetrating explosive injuries. Thoracic stab wounds consistently show the highest rates of survival after EDT.^{5,7,12-14} This is theoretically as a result of the decreased amount of tissue damage related to the weapon and the ability to quickly identify anatomic structures and injuries. Penetrating firearm injuries are more likely to result in death because of increased tissue damage from the missile and concussive surrounding forces. Patients with firearm injuries are more likely to have multiple wounds, and the depth of penetration is increased in comparison to stab wounds. One published cohort of combat casualties from explosive penetrating injuries reported similar survival rates to those after firearm-related penetrating injuries.¹⁴

The location of the penetrating injury helps determine the futility of EDT. A trend toward increased survival rates in patients with thoracic injuries was found in historical data.^{4,5,14-23} Isolated cardiac wounds have the highest survival rate after EDT, with approximately 17% of patients surviving the procedure.⁵ Penetrating abdominal injuries have beneficial outcomes when EDT is performed to cross-clamp the aorta, with survival rates in the midteens.^{7,14,24,25} Extremity injuries rarely require EDT because the use of a tourniquet can control the hemorrhaging until the patient can be transported to the operating room. When EDT is used for traumatic extremity exsanguination survival rates range from 10% to 25%.¹⁴ Patients in cardiac arrest associated with head injuries, especially those with open cranial wounds, have dismal survival rates and are considered poor candidates for further resuscitative efforts, including EDT.^{5,9}

The type of cardiac electrical activity can be helpful in determining who may benefit from EDT. Battistella and colleagues²⁶ reviewed 604 patients undergoing cardiopulmonary resuscitation (CPR) for traumatic cardiopulmonary arrest and found that of the 212 patients who were in asystole, none survived. Fulton and associates²⁷ found that of patients in traumatic arrest, survival was improved when the patients exhibited ventricular fibrillation, ventricular tachycardia, or pulseless electrical activity rather than asystole or an idioventricular rhythm. In another study of EDT for traumatic arrest, asystole, idioventricular rhythm, or severe bradycardia was indicative of poor outcomes or an unsalvageable patient.⁴

The duration of pulselessness prior to EDT has traditionally been used as a decision point. With traumatic injury, survival rates and meaningful neurologic outcomes diminish as the duration of CPR increases. The traditional dogma is that any trauma patient who has undergone CPR for longer than 15 minutes has an exceedingly dismal survival rate and further resuscitation should be considered futile.^{4,6,12,13,27-30} Guidelines from 2013 have questioned the 15-minute dogma and consensus timing on futility of the procedure remains elusive.^{5,31} It is recommended that each institution should develop protocols directing futility decision as it pertains to timing of pulseless activity prior to arrival of the patient in the ED.

Perhaps the most critical determinant of the appropriateness of EDT is whether the patient demonstrates “signs of life.” Signs of life are objective physiologic parameters that are present in patients who survive EDT. They include pupillary response, extremity movement, cardiac electrical activity, measurable or palpable blood pressure, spontaneous ventilation, or the presence of a carotid pulse. The presence of one or more of these indicators has been associated with good neurologic outcomes and increased rates of survival.^{3-11,32}

Although survival remains the ultimate gauge of the effectiveness of EDT, it is also essential to consider quality of life, especially neurologic function of the patient. It is somewhat surprising that survivors of EDT generally have good neurologic outcomes. Rhee and colleagues⁸ reported that 280 of 303 (92.4%) patients discharged after EDT were neurologically intact. It is not possible to accurately predict which patients are likely to survive intact, but the study by Branney and coworkers⁷ demonstrated that all survivors with full neurologic recovery had respiratory effort at the scene, and 75% still had respiratory effort on arrival at the ED. The presence or absence of a palpable pulse was not an absolute prognostic indicator in this study. The first 24 hours after EDT rapidly demonstrates which patients are likely to become long-term survivors. Baker and associates¹⁶ showed that with 168 emergency thoracotomies for mixed trauma, most patients with fatal injuries died within 24 hours. Of patients surviving the first 24 hours, 80% (33 of 41) lived and were discharged from the hospital. Full neurologic recovery occurred in 90% of these survivors. Overall only 2.4% (4 of 168) remained severely disabled or in a persistent vegetative state. Guidelines from 2015 show 90% of penetrating trauma patients surviving EDT were neurologically intact on discharge, although this rate falls to near 60% in blunt trauma.⁵

Cardiac Injuries—Penetrating

Sixty percent to 80% of cardiac stab wounds result in pericardial effusion regardless of the presence of shock.³³ Tamponade can occur if the wound is smaller than 1 cm in size, depending on which chamber is involved. Wounds larger than 1 cm usually

continue to bleed regardless of which chamber is involved. Low-pressure atrial wounds generally form a thrombus before tamponade develops. The thicker-walled left ventricle may spontaneously seal stab wounds up to 1 cm in length. As little as 60 to 100 mL of blood acutely filling the pericardium will impede diastolic filling, reduce stroke volume, decrease cardiac output, and increase release of catecholamine. Catecholamine release may mask the severity of illness because it maintains blood pressure through an increase in peripheral vascular resistance. In penetrating cardiac injury, the right ventricle is the chamber most likely to be involved because of its anterior location, followed by the left ventricle and the atria.^{34,35}

The progression from compensated cardiac function to uncompensated tamponade can be sudden and profound. Although one may suspect tamponade based on well-described signs, clinical diagnosis of pericardial tamponade in an unstable trauma patient is difficult because of the combined effect of hemorrhagic and cardiogenic shock. The classic signs of Beck's triad (distended neck veins, hypotension, and muffled heart sounds) described in 1926³⁶ have limited diagnostic value for acute penetrating cardiac trauma.³⁷ The most reliable signs of tamponade are elevated central venous pressure, hypotension, and tachycardia.

The advent of ultrasound and the focused assessment with sonography in trauma (FAST) examination has improved the diagnosis of pericardial effusion and tamponade. Findings indicative of tamponade include the presence of pericardial fluid with right atrial or ventricular collapse during diastole (Fig. 18.1). FAST is a rapid bedside screening examination used to detect hemoperitoneum and hemoperitoneum and is now important in the evaluation of unstable trauma patients.^{38,39} From data collected in 1540 patients, Rozynski and associates⁴⁰ reported 100% sensitivity and specificity in detecting pericardial and peritoneal fluid in a hypotensive, unstable trauma patient.

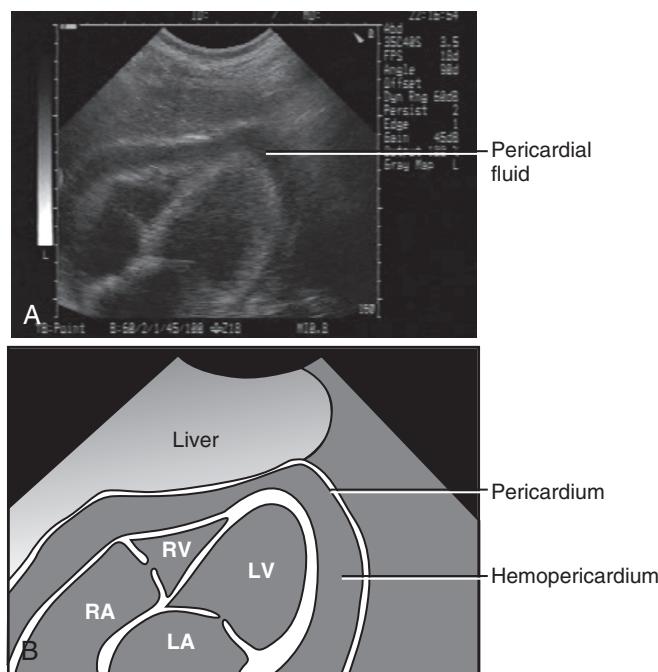


Figure 18.1 A, Bedside ultrasound demonstrating the hemopericardium. B, Artist's drawing of the chambers of the heart, the pericardium, and the hemopericardium as seen on ultrasound. LA, Left atrium; LV, left ventricle; RA, right atrium; RV, right ventricle.

Ultrasound can have rare false-negative results when pericardial fluid from a cardiac injury decompresses into the thoracic cavity through a wound in the pericardium.⁴¹ A 2015 study by Inaba and colleagues showed a high sensitivity and negative predictive value of FAST exam in determining which patients will not benefit from EDT.⁴² In this study the likelihood of survival if pericardial fluid and cardiac motion were both absent was zero.

After EDT for penetrating cardiac wounds, survival is also related to the mechanism of injury. Patients with stab wounds fare better than do patients with gunshot wounds. Rhee and colleagues⁸ noted that 16.8% of patients with stab wounds survived to hospital discharge after EDT. Branney and coworkers⁷ reported a 29% survival rate in stab wound patients with tamponade, and a 15% survival rate in those without tamponade.

In contrast, gunshot wounds are often large injuries unable to seal themselves; tamponade occurs in only 20%. Patients with penetrating cardiac injuries from gunshot wounds are more likely to initially be seen with profoundly compromised hemodynamics. In addition, the increasing popularity of larger-caliber weapons has made it more difficult to resuscitate patients with gunshot wounds to the chest. Of 112 patients with gunshot wounds to the heart,⁷ only 2% survived neurologically intact.

Cardiac Injuries—Blunt

Blunt trauma to the heart can range from minor contusion to cardiac rupture. The most common cause of death after nonpenetrating cardiac injuries is myocardial rupture, and in approximately 25% of such patients the ascending aorta is ruptured simultaneously.³³ Branney and coworkers⁷ observed a 2% survival rate in blunt trauma patients resuscitated with EDT. Those who survived had vital signs present in the field. The poor outcomes associated with this type of injury are a result of the poor cardiac function caused by myocardial contusion, even if the hemorrhage has been treated.

Pulmonary Injuries

Pulmonary injuries can be divided into three types: parenchymal, tracheobronchial, and large vessel. Parenchymal and tracheobronchial injuries rarely require EDT because they are either rapidly fatal or treated initially by tube thoracostomy. Tracheobronchial injury is more common in blunt than in penetrating trauma. Bertelsen and Howitz⁴³ reviewed 1128 patients at autopsy and found only three to have this injury. The airway is usually maintained, even with complete transection. The stiff tracheobronchial cartilage tends to hold the lumen open, and the paratracheal and parabronchial fasciae preserve the relationship of the proximal to distal bronchi. Ninety percent of tracheobronchial tears occur within 2.5 cm of the carina and most commonly involve the main stem bronchi. Complete division of the trachea is extremely rare. Depending on the size and location of the injury, patients may have massive hemoptysis, airway obstruction, pneumomediastinum, pneumothorax, or tension pneumothorax. Massive subcutaneous emphysema and pneumomediastinum are usually seen, although up to 10% of patients with this injury have no abnormal findings on the initial radiograph.⁴⁴ If hemorrhage is profuse or if the site of the injury can be determined, use of a bifid endotracheal tube or unilateral intubation of a main stem bronchus will help secure the airway.

Lacerations of the lung parenchyma that are not accompanied by injury to major vessels generally respond to tube thoracostomy. If the initial chest tube drainage is more than 1500 mL or if there is persistent hypotension or cardiac arrest, consider immediate thoracotomy. For pulmonary injuries, survival after EDT is also related to the mechanism of injury. Branney and coworkers⁷ reported a 17% survival rate after pulmonary stab wounds, 3% after gunshot wounds, and 5% after blunt trauma.

AIR EMBOLISM

Air embolism is a complication of pulmonary parenchymal injuries that may require immediate thoracotomy if the patient is hemodynamically unstable. The development of air embolism after penetrating injuries of the lung is often insidious, and the diagnosis is usually made at the time of thoracotomy.⁴⁵ Preoperative and postmortem diagnosis of air embolism is difficult, and it is likely that most air emboli are not detected. Air embolism is confirmed at thoracotomy by needle aspiration of a foamy air-blood mixture from the left or right ventricle or by visualization of air within the coronary arteries.

Air embolism may appear in either the right or the left side of the circulatory system. Involvement of the right side of the circulation is referred to as *venous* or *pulmonary* air embolism. Generally, venous air is well tolerated, but death can occur when the volume of air reaches 5 to 8 mL/kg. The rate at which air moves into the circulation and the body's position are important determinants of the volume that can be tolerated. If the body's position allows dispersion of air into the peripheral circulation, more air can be tolerated, although the damage to peripheral structures and end-organs can be extensive. Rapid death usually results from obstruction of the right ventricle or the pulmonary outflow tract. Injuries to the vena cava or the right ventricle can also create portals of entry into the right circulatory system.

Air embolism involving the left side of the circulatory system is referred to as *arterial* or *systemic* air embolism. The lethal volume depends on the organs to which it is distributed. As little as 0.5 mL of air in the left anterior descending coronary artery can lead to ventricular fibrillation. Two milliliters of air injected into the cerebral circulation can be fatal. The formation of traumatic bronchovenous fistulas creates potential entry points for air to move into the left side of the circulatory system. The only requirement is the formation of an air-blood gradient conducive to the inward movement of air. Although lowered intravascular pressure from hemorrhage is a risk factor, the most important element in all reports of air embolism has been the use of positive pressure ventilation.⁴⁶

In a review of 447 cases of major thoracic trauma, Yee and coworkers⁴⁷ found adequate chart data to suggest the diagnosis of air embolism in 61 patients. Approximately 25% of patients with air embolism have blunt trauma, with associated lung injury secondary to multiple rib fractures or hilar disruption. The overall mortality is higher than 50%.

The diagnosis of air embolism is easily overlooked because the signs and symptoms are similar to those of hypovolemic shock. Two valuable signs that are present in 36% of patients are hemoptysis and the occurrence of cardiac arrest *after intubation and ventilation*. The development of focal neurologic changes, seizures, or central nervous system dysfunction in the absence of head injury is also suggestive of the diagnosis.⁴⁸ Overall, the diagnosis is subtle and must be considered when

there is no evidence of the more common causes of extremis in a trauma patient.

Blunt and Penetrating Abdominal Injury

In the setting of penetrating abdominal injury, thoracotomy with cross-clamping of the thoracic aorta has been advocated as a means of controlling hemorrhage, redistributing blood flow to the brain and heart, and reducing blood loss below the diaphragm. Unfortunately, aortic cross-clamping can also have detrimental effects. Kralovich and colleagues⁴⁹ studied the hemodynamic consequences of aortic occlusion in a swine model of hemorrhagic arrest. There was no difference between groups in return of spontaneous circulation; however, the occluded aorta group experienced statistically greater impairments in left ventricular function and systemic oxygen utilization in the postresuscitation period. Branney and coworkers⁷ found that 8 of 76 patients undergoing EDT for *penetrating abdominal injury* survived neurologically intact. More recently, Seamon and colleagues²⁵ achieved a 16% survival rate with good neurologic outcomes (8 of 50 patients) when EDT was used before laparotomy for abdominal exsanguination from trauma. Of note, none of the survivors in this study were in cardiac arrest at the time of EDT, but they did have severe hemorrhagic shock, and six of the eight had unmeasurable blood pressure. The resurgence of resuscitative endovascular balloon occlusion of the aorta (REBOA) has changed many institutional trauma algorithms dealing with exsanguinating abdominal and pelvic hemorrhage.⁵⁰ Current recommendations suggest that EDT be performed judiciously in patients with abdominal trauma as an adjunct to definitive repair of the abdominal injury.

Open-Chest Resuscitation for Nontraumatic Arrest

At present, less than 6% of CPR attempts conducted outside hospital special care units result in survival.⁵¹ The first case of a human survivor of open-chest cardiac massage (OCCM) was reported in 1901. In 1960, Kouwenhoven and associates⁵² published favorable survival rates with closed-chest CPR as opposed to OCCM. After further refinement by Pearson and Redding, closed-chest CPR gradually became the preferred method of cardiac compression.⁵³

The goal of CPR is to restore coronary perfusion pressure (CPP), which is the prime determinant for return of spontaneous circulation as established in animal models. Paradis and associates⁵⁴ found that humans need a minimal CPP of 15 mm Hg to achieve return of spontaneous circulation. Although a CPP of 15 mm Hg does not guarantee return of spontaneous circulation, there is 100% failure of resuscitation if CPP is below this level. Despite the limited number of human studies on OCCM, its hemodynamic superiority over closed-chest CPR is compelling. Del Guercio and coworkers⁵⁵ measured cardiac output during both closed-chest CPR and OCCM in in-hospital cardiac arrest patients. OCCM produced a mean cardiac index of 1.31 L/min per m² as opposed to 0.6 L/min per m² during closed-chest CPR. Boczar and colleagues⁵⁶ further examined 10 patients who were unresponsive to closed-chest CPR and measured CPP during closed-chest CPR followed by OCCM. Mean CPP in the closed-chest group was 7.3 mm Hg versus 32.6 mm Hg in the open-chest group. All patients achieved a CPP of at least 20 mm Hg at some time during their OCCM phase. This easily surpassed the minimal CPP required for

return of spontaneous circulation. Outcomes after OCCM have not been well established. Animal models suggest not only improved hemodynamic parameters, but also a possible increase in 24-hour survival rates.⁵⁷ However, neurologic outcomes are unknown, and the American Heart Association guidelines for CPR do not promote the regular use of OCCM in patients with out-of-hospital cardiac arrest.⁵¹

At present, the precise indications for open-chest resuscitation after nontraumatic arrest are not well defined, and the procedure is not considered the standard of care. Despite demonstrated hemodynamic superiority in both animal and human models of open-chest versus closed-chest CPR, outcome benefit is lacking. There is a paucity of human data evaluating the window of time during which this treatment can be effective.

Nontraumatic Hypothermic Cardiac Arrest

In the setting of cardiac arrest from hypothermia, one can consider the use of EDT and OCCM. Cardiopulmonary bypass (CPB) or extracorporeal membrane oxygenation are the most rapid methods of core rewarming,⁵⁸ but these methods are sometimes not available immediately. Open thoracotomy with mediastinal irrigation has been used successfully in cases of severe hypothermia with cardiac arrest. Brunette and McVaney⁵⁹ reported 11 patients with hypothermic cardiac arrest, 7 of whom underwent EDT with OCCM and mediastinal rewarming. Five patients survived, and all had positive neurologic outcomes despite cardiac arrest times of between 10 and 90 minutes (although one patient died of gastrointestinal hemorrhage and sepsis following resuscitation; the other four patients survived with full neurologic recovery). The other four patients who did not undergo EDT did not survive despite being taken promptly to the operating room for CPB rewarming. Although the number of cases is limited, this study is evidence that OCCM can provide prolonged hemodynamic support and good neurologic outcomes. It should be noted that similar case reports also exist in which closed-chest CPR was maintained for prolonged periods and resulted in successful hypothermic resuscitation.⁶⁰ EDT with mediastinal irrigation can produce core rewarming rates as fast as 8°C/hr, with the heart and lungs preferentially being rewarmed first.⁵⁹ Mediastinal irrigation involves heating sterile saline in a microwave oven to 40°C and then pouring it slowly over the heart and into the thorax. Performing a thoracotomy for hypothermic arrest does not preclude the use of CPB inasmuch as it was subsequently used after EDT in three of the survivors from the Brunette and McVaney study.⁵⁹

EQUIPMENT

Carefully select the instruments to be included in the EDT equipment tray. See Review Box 18.1 for a complete list.

PROCEDURE

Preliminary Considerations

All trauma patients arriving at the ED with hypotension must be assumed to be hypovolemic and should be treated accordingly. Rapidly exclude other causes as well, including tension

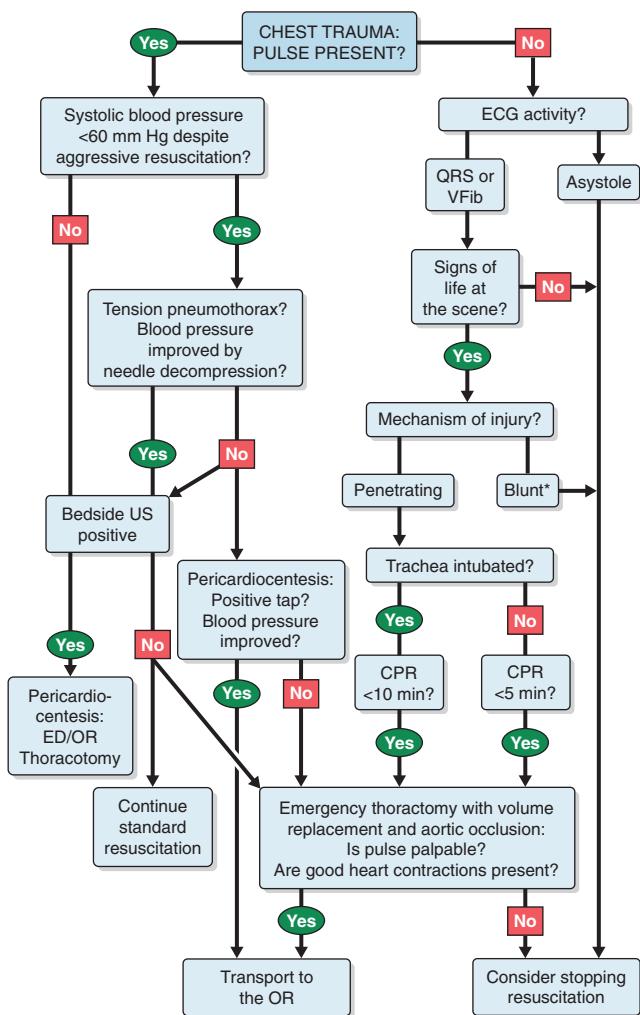


Figure 18.2 An algorithmic approach to chest trauma. *Pulseless blunt trauma management is controversial with some data supporting stopping resuscitation immediately, whereas recent data recommend EDT if CPR has been ongoing less than 5 minutes. QRS, Organized electrical activity; TAP, pericardial tap yielding blood; US, ultrasonography; VFib, ventricular fibrillation.

pneumothorax, cardiac tamponade, air embolism, and neurogenic or cardiogenic shock. A useful algorithmic overview of the approach to chest trauma is presented in Fig. 18.2. The use of autotransfusion, if available, has several benefits, but its use is not widespread or considered standard.⁶¹

Airway Control

Intubate the patient orotracheally, if possible, but be aware that access to the thoracic organs, surgical repairs, or surgical procedures may be hampered by frequent inflations of the left lung. If necessary, selectively intubate the right lung by blindly advancing a standard single-lumen endotracheal tube to a depth of 30 cm (measured from the corner of the mouth) in adult patients.⁶² Although the left lung and the right upper lobe are not ventilated with the tracheal tube in this position, both animal studies and data from humans suggests that selective right lung ventilation provides adequate oxygenation and ventilation for at least 60 minutes.⁶² With the left lung deflated

one can expedite thoracotomy by maximizing space in the left thoracic cavity. Keep in mind that extending the thoracotomy into the right thoracic cavity may necessitate switching to bilateral lung ventilation or left lung ventilation to allow maximum right thoracic exposure.

Anesthesia and Amnesia

Comatose patients undergoing resuscitation may regain consciousness during successful EDT, but this awareness may not be apparent if they are still pharmacologically paralyzed. Anticipate and recognize this phenomenon and administer adequate analgesic, amnestic, and muscle-relaxing agents to a ventilated patient who may also be in shock. No specific regimen has been studied, but ketamine appears to be an ideal agent to use in the ED. It is prudent to administer anesthetic agents routinely if a paralyzed patient demonstrates perfusion during resuscitation. This is not only humane but decreases systemic oxygen consumption.

Anterolateral Thoracotomy Incision

Manually ventilate the patient during the procedure. Ask an assistant to pass a nasogastric tube, which helps differentiate the esophagus from the aorta, but do not allow this procedure to delay thoracotomy. If CPR is being performed, ask an assistant to continue closed-chest compressions up to the point of making the initial incision. Take universal precautions to avoid blood exposure and use a suction catheter to minimize contact with blood. Sterile gloves (consider double-glove protection), gown, mask with an eye shield, and an operative surgical cap are recommended for the procedure.

Prepare the skin of the left anterior aspect of the chest with antiseptic if readily available. Wedge towels or sheets under the left posterior part of the chest and place the patient's left arm above the head (Fig. 18.3A). On the left side of the chest, make an anterolateral incision at the fourth to fifth intercostal space with a No. 20 blade scalpel (Fig. 18.4, step 1). Do not take the time to count ribs; simply estimate the location to be just beneath the nipple in males and at the inframammary fold in females (see Fig. 18.3). It is important to establish wide exposure by beginning the incision on the right side of the sternum and extending the skin incision past the posterior axillary line. Beginning here will save time if the right side of the chest needs to be opened as well. Inadequate exposure, rib fractures, and additional delays occur when the skin incision is too limited. With the first sweep of the scalpel, separate skin, subcutaneous fat, and the superficial portions of the pectoralis and serratus muscles.

Cut the intercostal muscles with scissors to expose the thoracic cavity (see Fig. 18.4, step 2). Use scissors to divide the intercostal muscles because the risk for lung laceration is greater when a scalpel is used. Make the incision just over the top of the rib to avoid the intercostal neurovascular bundle. Just before opening the pleura, stop ventilations momentarily. This will allow the lung to collapse away from the chest wall. Should the internal mammary artery be transected during the procedure, hemorrhage is generally minimal until after perfusion is reestablished, at which time bleeding may be profuse. If actively bleeding, the internal mammary artery should be ligated or clamped. Do not forget to address the internal mammary artery if perfusion is reestablished because this can be a source of significant bleeding.³²

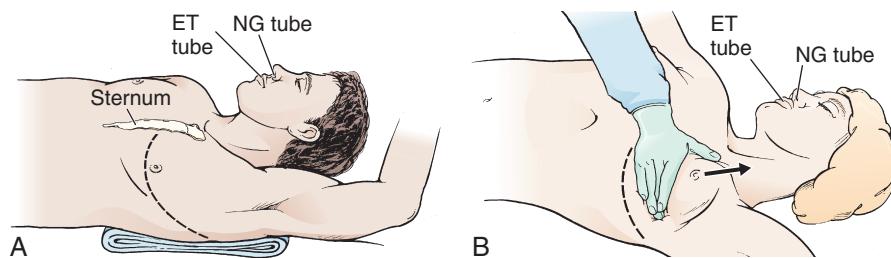


Figure 18.3 Left anterolateral thoracotomy. **A**, Place several towels or sandbags under the left scapula and raise the arm above the head. The patient should be intubated. Insert a nasogastric (NG) tube to differentiate the esophagus from the aorta. Make a left anterolateral submammary incision. **B**, Dashes indicate the incision site in the inframammary fold in women. *ET*, Endotracheal.

Resuscitative Thoracotomy General Technique

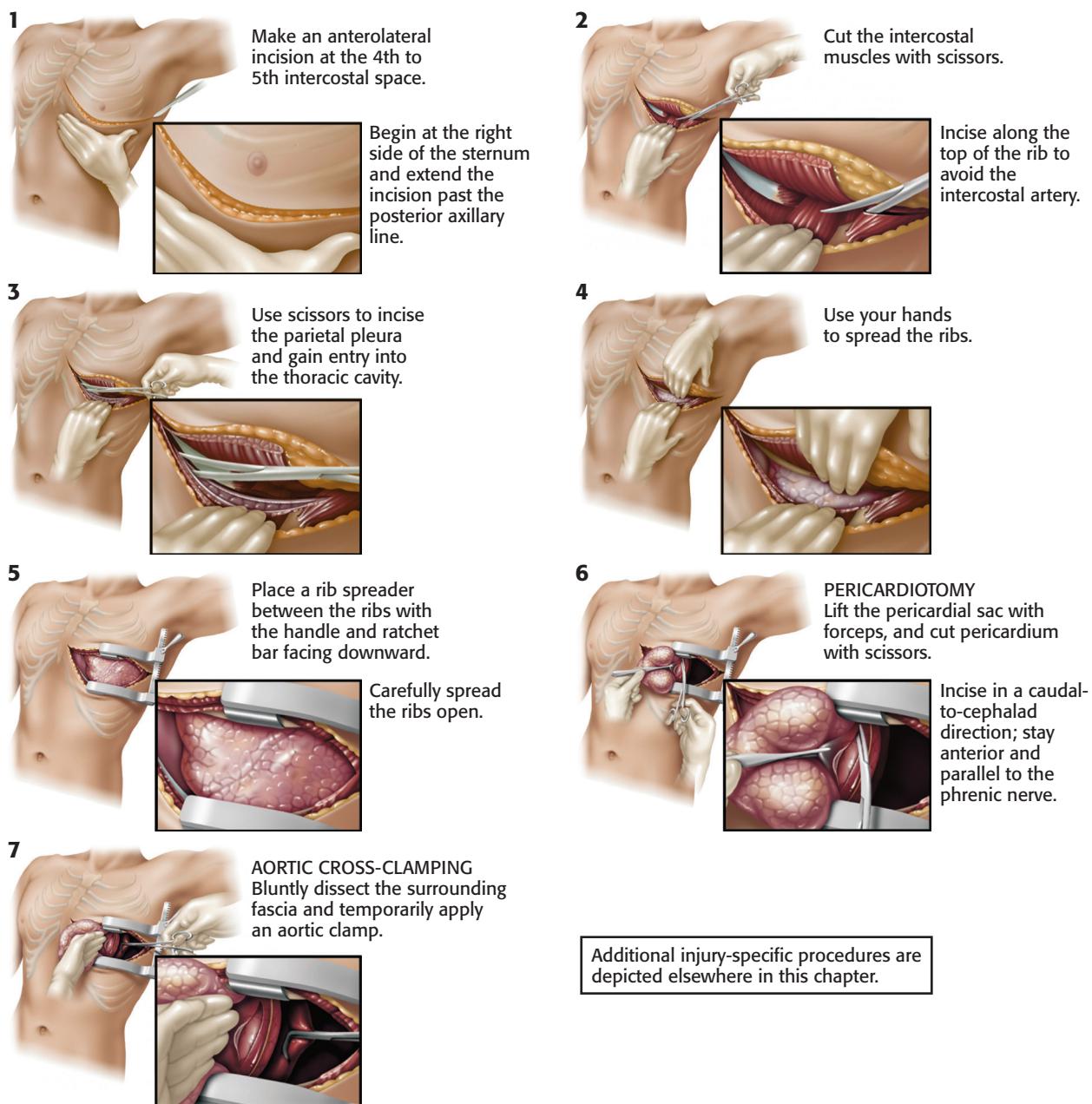


Figure 18.4 Resuscitative thoracotomy, general technique. (From Custalow CB: Color atlas of emergency department procedures, Philadelphia, 2005, Saunders.)

After entering the pleural cavity, gain good exposure. Karmy-Jones and associates⁶³ found that 20% of their patients undergoing EDT via the anterolateral approach needed to have the initial incision extended. To gain better exposure first use your hands to open the chest cavity. Then place a Finochietto retractor (rib spreader) between the ribs with the handle and the ratchet bar directed downward toward the axilla (see Fig. 18.4, step 5). If the retractor were to be placed with the handle up, the ratchet bar would prevent extension of the incision into the right side of the chest. Ribs may be broken during spreading, so be careful to not get cut on the sharp bone edges. If massive hemothorax is encountered, remove the clots manually, suction out the blood, and use towels to absorb any blood spilling from the chest. If the site of injury is to the right of the heart and cannot be reached, extend the incision into the right side of the chest with a Gigli saw, Liebsche knife, sternal osteotome, or standard trauma shears. Before performing EDT it would be prudent to familiarize oneself with the instruments included in the EDT tray, but do not take the time for this during an actual case.

Pericardiotomy

For a patient in cardiac arrest, if there is no other obvious injury in the chest and the myocardium cannot be visualized, open the pericardium. It may be difficult to definitively rule out pericardial tamponade by visual inspection alone. If in doubt, use forceps to elevate a portion of pericardium and carefully incise it to assess for hemopericardium.

If you are confident that there is no pericardial tamponade, leave the pericardial sac closed while you address other life-threatening injuries. Opening the pericardium increases the risk for complications such as delay in the onset of cardiac compressions, damage to the myocardium or coronary vessels, or cutting of the left phrenic nerve. Previous pericardial disease may also have caused adhesions, and if you attempt to separate these adhesions rapidly, you can tear the atria or right ventricular wall. The incidence of traumatic rupture of the atria or the right ventricle during massage is greater when the pericardium is open. Furthermore, with an intact pericardium pressure is distributed over a larger area, and the pericardial fluid seldom allows compressing fingers to remain in one spot for a prolonged period.

Perform pericardiotomy if tamponade is present or suspected. This procedure is performed anterior and parallel to the left phrenic nerve (see Fig. 18.4, step 6). Begin the incision near the diaphragm to avoid injury to the coronary arteries. Lift the pericardial sac with toothed forceps, and use scissors to make a small hole. Extend the incision with scissors in a cephalad direction along the anterior aspect of the pericardium. Extend the incision so that it reaches from the apex of the heart to the root of the aorta. When the pericardium is under tension, it may be difficult to grasp the pericardium with forceps. In this case, use sharp, straight Mayo scissors to divide the pericardium by layers. If the heart is in arrest, speed is important, so use sharp scissors to “catch” the pericardium and start the pericardiotomy. To do this procedure, hold the point of the scissors almost parallel to the surface of the heart and use enough pressure to create a wrinkle in the pericardium to puncture it as the scissors move forward. Apply moderate pressure to puncture the fibrous pericardium. Be cautious because if the point of the scissors is unnecessarily angled toward the heart, the sudden “give” that occurs when you

open the pericardium may result in laceration of the myocardium. Remove clots of blood from the pericardial sac with a sweeping motion using your gloved hand, sterile lap sponges, or gauze pads. If cardiac repair or cardiac compressions are needed, deliver the heart from the pericardial sac. To do this, place your right hand through the pericardial incision and encircle the heart, pull it into the left side of the chest, and place the pericardial sac behind the heart.

Internal Cardiac Defibrillation

It is not uncommon to encounter cardiac dysrhythmias during EDT resuscitative efforts. Recommendations for internal defibrillation are the same as those for external defibrillation: ventricular fibrillation and tachycardia without pulses are immediate indications for defibrillation. With an open chest, internal defibrillation is the procedure of choice.

To perform internal defibrillation, place the *internal paddles* on the anterior and posterior aspects of the heart. The current is delivered through the circular tips of the paddles onto the surface of the heart. There is decreased electrical impedance with direct myocardial contact, and as a result less energy is needed than with standard defibrillation (typically 10 to 50 J). If internal paddles are not available, perform defibrillation in the usual manner with external paddles or electrodes.

Direct Cardiac Compressions

Three techniques for cardiac compression have been described: one-handed compression, one-handed sternal compression, and two-handed (bimanual) compression (Fig. 18.5). To perform the one-handed compression method, place your thumb over the left ventricle, the opposing fingers over the right ventricle,

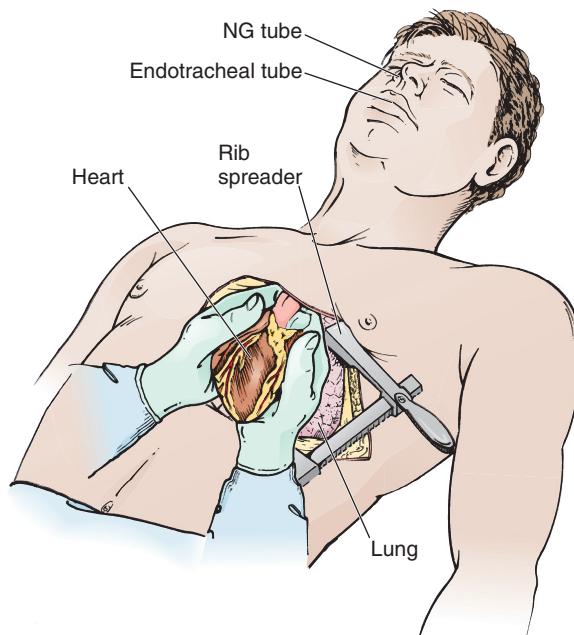


Figure 18.5 Two-handed method of cardiac massage. Compress the ventricles toward the interventricular septum. Note how the hands flank the left anterior descending artery, which overlies the septum. Avoid using excessive fingertip pressure or lifting the heart, which slows ventricular filling by distorting the soft atrial-caval junction. NG, Nasogastric.

and your palm over the apex of the heart. To perform one-handed sternal compression, hold your fingers flat. Keep the fingers tightly together to form a flat surface over the left ventricle and compress the heart up against the sternum with your fingers. To perform two-handed compression, cup the left hand and place it over the right ventricle. Hold the fingers of the right hand tightly together to form a flat surface supporting the left ventricle. Push the flat surface of your right-hand fingers to compress the heart against the cupped surface of the left hand. The bimanual technique has been shown to be consistently superior.⁶⁴

A difference of opinion exists regarding the optimal rate at which the heart should be compressed. Some recommend a rate of 50 to 60 compressions/min; however, no physiologic data support such a recommendation. American Heart Association guidelines for closed-chest CPR recommend a rate of at least 100 compressions/min.⁵¹ It is conceivable that this would also apply to OCCM.

It is important to remember the following points while performing cardiac compression:

1. Use the entire palmar surface of the fingers. Avoid fingertip pressure.
2. For each method, adjust the force of compression so that it is perpendicular to the plane of the septum. The anterior descending coronary artery is located over the interventricular septum, making this a helpful landmark to orient your hand properly.
3. Position your fingers so that the coronary arteries will not be occluded.
4. Venous filling of the heart is especially sensitive to changes in position. Maintain a relatively normal anatomic position of the heart to prevent kinking of the vena cava and pulmonary veins. Do not angle the heart more than 30 degrees into the left side of the chest.
5. It is essential to completely relax the heart between compressions to allow it to refill completely.

Control of Hemorrhagic Cardiac Wounds

To partially control active bleeding from a ventricular wound, place one finger over the wound and use the other hand to stabilize the beating heart. This maneuver buys time while you begin to repair the injury and continue with resuscitation. If the heart is not beating, you may perform closure of the injury before resuscitation and defibrillation, although this is controversial. If you elect to repair the injury before attempting to restart the heart, perform intermittent cardiac massage. Surgical staples can be used to close a ventricular wound and are an extremely rapid method for controlling hemorrhage (Fig. 18.6).⁶⁵ This technique is particularly useful with large or multiple lacerations. Another advantage is that stapling does not expose the operator to the risk associated with needlestick. Macho and coworkers⁶⁶ reported a 93% success rate in temporarily controlling hemorrhage in 28 patients (33 lacerations) with penetrating injuries to both the atria and ventricles by using a standard skin stapler with wide (6-mm) staples placed at 5-mm intervals (Auto-Suture 35W, US Surgical Corp., Norwalk, CT). The rotating long neck of the Ethicon Proximate Quantum Skin Stapler (Model PQW-35, Ethicon, Inc., Somerville, NJ) is helpful in obtaining proper orientation of the staples during placement. The staples can be left in place and reinforced or replaced on further exploration in the operating room.

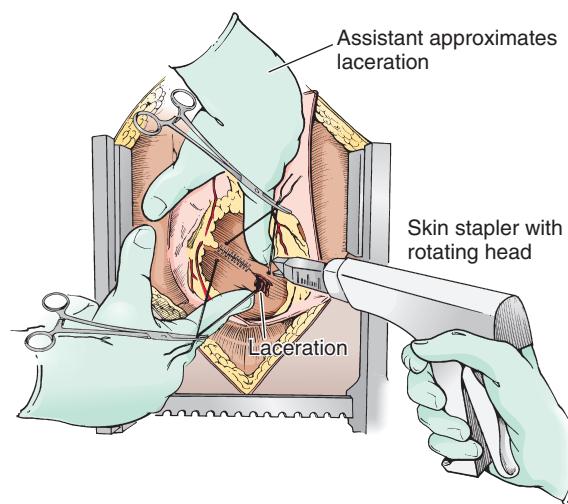


Figure 18.6 Technique of cardiac stapling to temporarily control hemorrhage. Ask an assistant to approximate the tissues with fingertip pressure, or as illustrated, use two half-horizontal sutures to approximate the wound edges and reduce bleeding. Use a skin stapler with wide (6-mm) staples and place them 5 mm apart. This technique may be used for atrial and ventricular lacerations. After stabilizing the patient's condition, revise the wound in the operating room.

Alternatively, repair the wound by placing several horizontal mattress sutures under the tamponading finger (Fig. 18.7). Polypropylene 2-0 or 3-0 monofilament (Prolene) suture is recommended for cardiac repair, but nonabsorbable silk can also be used. Avoid smaller sutures and nylon sutures. If multiple sutures are needed, lay them all in place before they are tied. This allows you to attain equal distribution of wound tension, which prevents tearing of the myocardium.⁶⁷ Alternatively, pass the suture underneath, over, and through Teflon pledgets to prevent the suture from cutting through the myocardium. Pledgets are especially important for reinforcement when the myocardium has been weakened by the blast effect of a bullet,⁶⁸ or when suturing the thinner-walled atria or right ventricle. An alternative to Teflon pledgets is to use small rectangles of pericardial tissue cut from the opened pericardium.

For large wounds that cannot be controlled with pressure, place an incomplete horizontal mattress suture on either side of the wound (Fig. 18.8). Cross the free ends to stop the bleeding. Then the actual reparative sutures can be placed accurately. It must be stressed that suturing the myocardium requires good technique. Excessive tension may tear the myocardium and aggravate the situation. Keys to success include using appropriately sized suture, obtaining a generous "bite" with the needle, and applying only enough tension to control the bleeding.

If exsanguinating hemorrhage is not controlled by the aforementioned methods, temporarily occlude inflow to the heart. Apply inflow occlusion intermittently for 60 to 90 seconds. During occlusion, the heart shrinks, hemorrhage is controlled, and you can place sutures in a decompressed injury. Two techniques that are useful are vascular clamping of the superior and inferior vena cava for partial inflow occlusion,⁶⁹ and the Sauerbruch grip (Fig. 18.9).⁷⁰ The Sauerbruch grip can be performed quickly with the added advantage of cradling and stabilizing the heart while you repair the wounds over either the ventricle or the left atrium. It involves occlusion of the

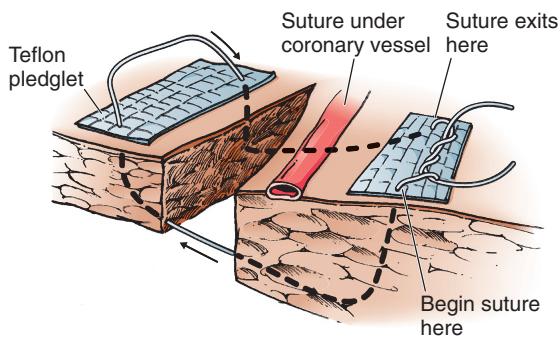


Figure 18.7 Technique of cardiac suture repair. Place multiple horizontal mattress sutures 6 mm from the edge of the wound before tying. Close the wound just enough to stop the bleeding. Use Teflon pledges on the cardiac surface, and pass all surface sutures through these reinforcements. Sutures come from underneath, lie over, then pass back through the pledges. Closure without pledges incurs the risk of sutures ripping through the contracting myocardium. Similarly, the use of simple vertical sutures should be discouraged because of the risk for suture dissection through the myocardium. For repairs near a coronary artery, take care to pass the suture under the artery. Note that rectangles of pericardial tissue may be substituted for ready-made Teflon pledges.

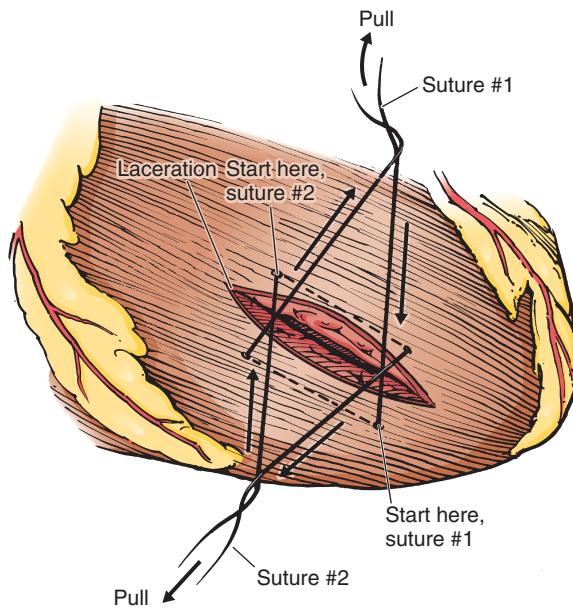


Figure 18.8 Control of hemorrhage with two widely placed incomplete mattress sutures. Ask an assistant to cross two half-horizontal sutures to bring the wound edges into apposition. By controlling the hemorrhage in this manner, the assistant's hands are outside the operative field and the edges of the wound are fully exposed. This facilitates more orderly closure of the wound. After the wound is repaired, the sutures may be either removed or tied to each other.

vena cava between the ring and middle fingers of the left hand to create partial occlusion of inflow. The Sauerbruch grip will interfere only with the repair of wounds involving the right atrium.

Another technique for temporarily controlling hemorrhage is to insert a Foley catheter (20 Fr with a 30-mL balloon) through a wound.⁷¹ After inserting the catheter, inflate the balloon, clamp the catheter to prevent air embolism, and apply

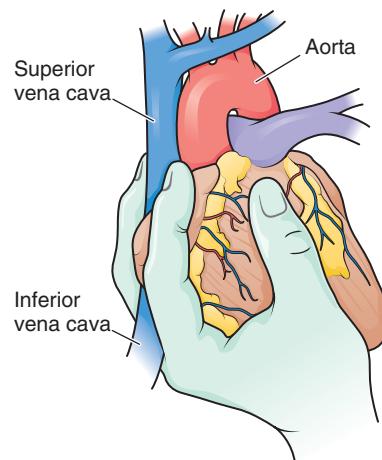


Figure 18.9 The Sauerbruch maneuver is the method of choice for reducing heavy bleeding from cardiac wounds. Occlusion of venous inflow is achieved by using the first and second, or second and third fingers as a clamp.

gentle traction (Fig. 18.10). Apply enough traction to slow the bleeding and provide an acceptable level to visualize and repair the wound. Excessive traction can pull the catheter out and enlarge the wound. The balloon will effectively occlude the wound internally. Use a purse-string suture to close the wound. When repairing the wound be careful with the suture needle because it can easily rupture the balloon. Temporarily pushing the balloon into the ventricular lumen during passage of the needle can be done to avoid this complication. Use normal saline when inflating the balloon because using air could result in air embolism if the suture needle ruptures the balloon.

Foley catheters have several advantages over other methods for controlling cardiac wounds. With the digital method, your fingertip will often slip if there is a strong heartbeat, you cannot visualize the wound during repair, and digital pressure significantly interferes with cardiac massage. Intermittent total venous inflow occlusion is an effective method of controlling bleeding and decompressing the heart, but such control will be at the expense of poor cardiac output. Attempting to elevate the heart for control and repair of posterior cardiac wounds often results in cardiac arrest by reducing both venous and arterial flow. With posterior injuries use of a Foley catheter does not require continued viewing after initial placement. If bleeding can be controlled, repairs in this location should await full-volume expansion or cardiopulmonary bypass.⁷² Regardless of location the most valuable feature of the Foley catheter is that you can control hemorrhage without interfering with cardiac compression. The catheter can also be used for infusion of fluids (see Fig. 18.10B).⁷³

To initially manage wounds of the atria, use partial-occlusion clamps (Fig. 18.11). Because of the thin structure and instability of the atrial wall, you will not be able to effectively stop bleeding with digital pressure. Injuries near the caval-atrial junction are not amenable to clamping; in this location, use a Foley catheter to tamponade the wound.⁷¹ Be careful not to obstruct atrial filling with the inflated balloon. Skin staples may also be used for closure of atrial wounds.⁶⁶

Wounds of the septa, valves, and coronary arteries require definitive repair in the operating suite. Hemorrhage from a coronary artery can generally be controlled with digital pressure. Avoid ligation of a coronary artery whenever possible.

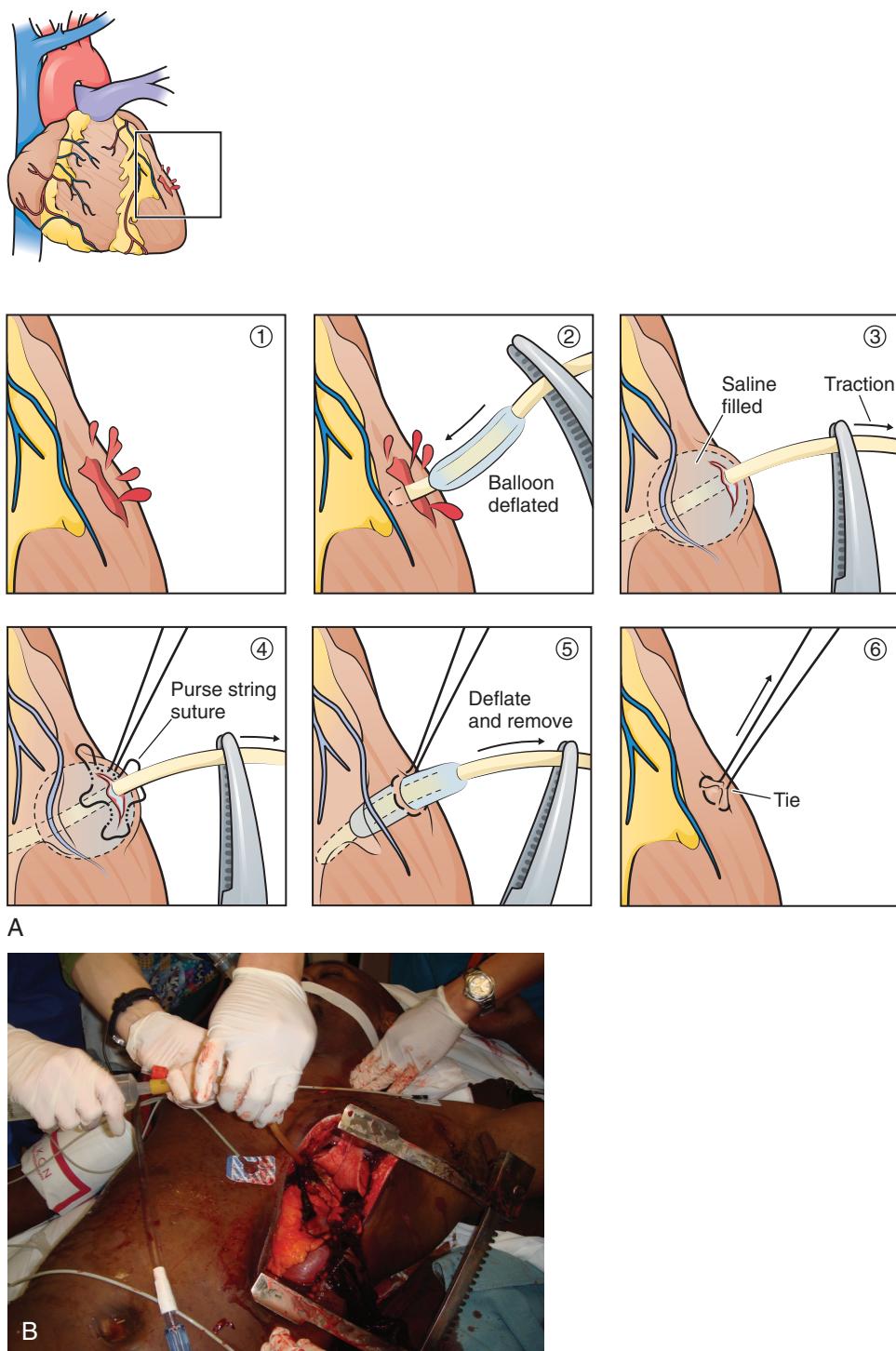


Figure 18.10 A, Serial illustration. Gentle traction on an inflated Foley catheter may control hemorrhage and allow repair. Inflate the balloon with saline while taking care to not rupture the balloon with the suture needle. This technique is particularly useful for injuries to the inferior cavoatrial junction, for posterior wounds, and during cardiac massage. Volume loading can be achieved by infusion of blood or crystalloid solution through the lumen of the catheter. Take care to avoid an air embolus through the lumen of the catheter during placement. **B,** Foley catheter in an atrial stab wound. Keep gentle traction on an inflated balloon and inject saline directly into the heart via the catheter. Note how difficult it is to identify structures in the chest cavity. The heart is collapsed and not beating, which makes even this organ hard to find. The aorta could not be isolated before stopping resuscitation efforts.

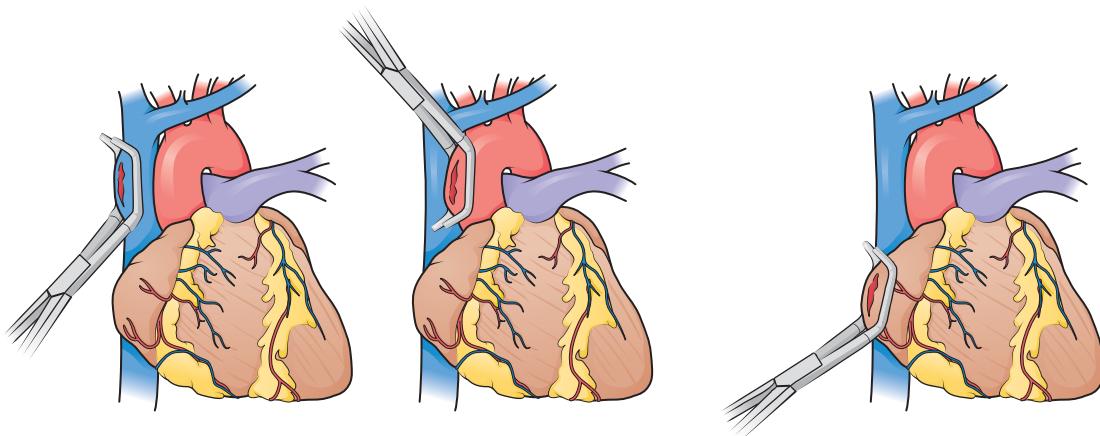


Figure 18.11 Use a partial-occlusion clamp in different locations for control of bleeding and subsequent repair.

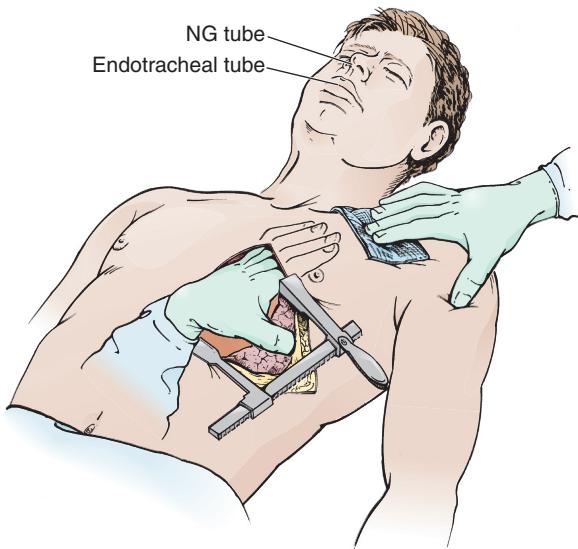


Figure 18.12 Cross-clamping for control of subclavian bleeding is difficult and time-consuming. Compression with laparotomy pads in the apical pleura from below and the supraclavicular fossa from above will control hemorrhage while the patient's condition is stabilized and the patient is transported to the operating room. NG, Nasogastric.

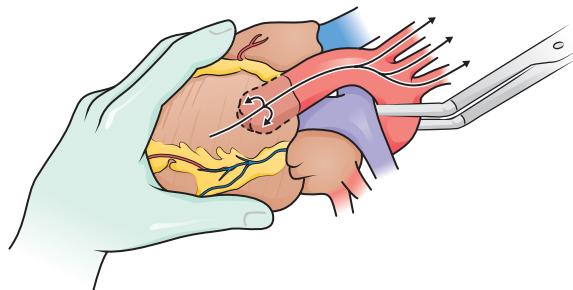


Figure 18.13 Manual cardiac massage and cross-clamping of the aorta can be used to increase coronary and cerebral perfusion selectively.

Control of Hemorrhagic Great-Vessel Wounds

Wounds of the great vessels can be controlled with digital pressure or partial-occlusion clamps. If desired, close small aortic wounds with 3-0 Prolene suture.⁷⁴ To prevent exsanguinating hemorrhage from the left subclavian artery, try to cross-clamp the intrathoracic portion of the artery. Cross-clamping of the right subclavian artery is very difficult. For injuries to this vessel, use laparotomy pads for compression in the apex of the pleura from below and the supraclavicular fossa from above (Fig. 18.12) to prevent further bleeding as the patient is stabilized and moved to the operating suite.⁶⁵

Aortic Cross-Clamping

For persistent hypotension (systolic blood pressure <70 mm Hg) after thoracotomy and pericardiotomy, perform temporary

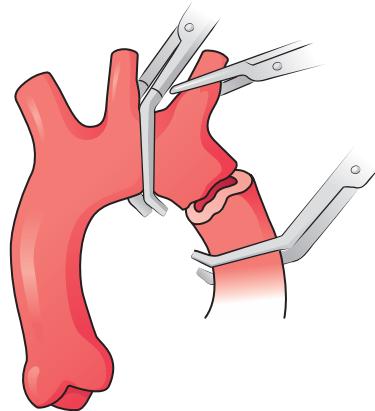


Figure 18.14 Traumatic rupture of the aorta is usually a fatal injury. Three clamps are required for control. Backbleeding will occur if fewer than three clamps are used.

occlusion of the descending thoracic aorta. This maneuver can maintain myocardial and cerebral perfusion (Fig. 18.13; see also Fig. 18.4, step 7), although Kravolich and colleagues⁴⁹ suggested that the benefit of significant improvement in CPP may be overstated. When the aorta has been injured by blunt trauma, selective clamping is necessary (Fig. 18.14). Aortic occlusion has a limited role in controlling hemorrhage below the diaphragm. In patients with a tense abdomen and massive

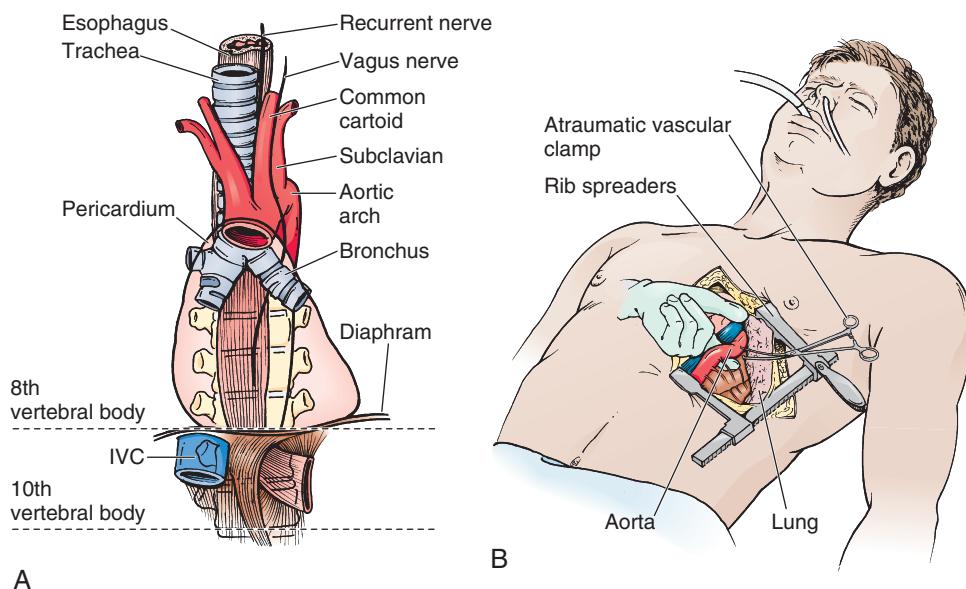


Figure 18.15 **A**, Identification of the aorta is very difficult during emergency department thoracotomy. If possible, first pass a nasogastric tube to help identify the esophagus. The aorta is in the posterior mediastinum, directly anterior to the vertebral bodies. The esophagus is anterior and slightly medial to the aorta. In the lower part of the thorax, both are covered on the anterolateral surface by the mediastinal pleura, which must be dissected before isolating the aorta for cross-clamping. **B**, Aortic cross-clamping. Using blunt dissection, spread the pleura above and below the aorta. Fully mobilize the vessel and clearly separate the esophagus before clamping. The aorta is the more posterior structure and is in contact with the vertebral bodies.

hemoperitoneum, aortic cross-clamping is beneficial when applied just before laparotomy.²⁵

The aorta can be very difficult to identify in an ED, especially when collapsed as a result of exsanguination. It is situated immediately anterior to the vertebrae and actually lies on the vertebral bodies themselves. The esophagus lies anterior and slightly medial to the aorta. Passing a nasogastric tube from above may help in identifying the esophagus. To expose the descending aorta, ask an assistant to retract the left lung in a superomedial direction. To achieve adequate exposure, it is sometimes necessary to divide the inferior pulmonary ligament (be careful not to injure the inferior pulmonary vein). Identify the aorta by advancing the fingers of the left hand along the thoracic cage toward the vertebral column. Open the mediastinal pleura and bluntly dissect the aorta away from the esophagus anteriorly and the prevertebral fascia posteriorly before clamping. To locate the aorta, use a DeBakey aortic clamp or a curved Kelly clamp for blunt dissection, and spread the pleura open above and below the aorta (Fig. 18.15). Alternatively, if excessive hemorrhage limits direct visualization, bluntly dissect with the thumb and fingertips. Separate the aorta from the esophagus, which lies medially and slightly anteriorly. It may be difficult to separate the esophagus from the aorta by feel in a hypotensive or cardiac arrest situation. When the aorta is completely isolated, use the index finger of the left hand to flex around the vessel and apply a large Satinsky or DeBakey vascular clamp with the right hand. Check brachial blood pressure immediately after the occlusion. If systolic pressure is higher than 120 mm Hg, slowly release the clamp and adjust it to maintain a systolic pressure of less than 120 mm Hg.²⁴



Figure 18.16 Use of a Conn aortic compressor is an excellent method for aortic occlusion because it is fast, does not interfere with the operative field, and is associated with minimal risk for injury. Alternatively, direct digital occlusion can be used, but this technique is more awkward.

Given the need for timely intervention, the simplest and most desirable approach to aortic occlusion is to have an assistant digitally compress it or use the aortic tamponade instrument (Fig. 18.16). The aortic tamponade instrument, however, may be applied blindly to the vertebral column and permits safe, quick, and complete aortic occlusion.⁷⁵ This technique may be most prudent when isolation of the aorta is difficult. The instrument's unique shape allows it to remain in place and to provide atraumatic occlusion with little interference in the

operative field when compared with digital compression. The degree of occlusion can be varied by the amount of pressure exerted by the operator.

Potential complications of aortic cross-clamping include ischemia of the spinal cord, liver, bowels, and kidneys. In addition, iatrogenic injury to the aorta and the esophagus may occur. Fortunately, these complications are infrequent. The metabolic penalty of aortic cross-clamping becomes exponential when occlusion time exceeds 30 minutes.⁷⁶ Whenever possible, unclamp the aorta for 30 to 60 seconds every 10 minutes to increase distal perfusion. Perform final release of the aorta gradually.

Management of Air Embolism

In those at risk for air embolism spontaneous ventilation is preferred. It is essential that the source of the air embolism be controlled rapidly. Place the patient immediately in the Trendelenburg (head-down) position to minimize cerebral involvement and direct the air emboli to less critical organs. If the chest injury is unilateral, consider isolating the injured lung by selectively intubating the contralateral lung. If this is unsuccessful, perform a left anterolateral thoracotomy. Flood the exposed thorax with sterile saline and look for bloody froth created during positive pressure ventilation to identify peripheral bronchovenous fistulas. Carry out a quick search for hilar injuries. If the source of the air embolism is not readily apparent, perform a contralateral thoracotomy. Once the bronchovenous communication is controlled, use a needle to aspirate the residual air that commonly remains in the left ventricle and the aorta. If the patient is hypotensive, consider cross-clamping the aorta. Be aware, though, that cross-clamping the aorta before controlling bronchovenous fistulas and removing residual air may result in further dissemination of air to the heart and brain.

Air emboli traverse capillary beds if the blood pressure is high enough. After controlling the bronchovenous fistula, produce a brief period of proximal aortic hypertension by cross-clamping the descending aorta. Maintain systemic arterial pressure with adequate fluid resuscitation. Vasopressors such as dopamine, epinephrine, or norepinephrine may be required to increase systemic pressure and facilitate the passage of air bubbles from left to right.⁷⁷

Maintain left atrial pressure at a high level. Keep the ventilator inspiratory pressure as low as possible, and use 100% oxygen to facilitate diffusion of nitrogen from emboli. Consider high-frequency ventilation, which allows the use of small volumes and has been used successfully in individual patients. The most important adjunctive therapy is hyperbaric oxygen. Although it is best to begin treatment within 6 hours of the traumatic insult, there are cases of success and improvement when hyperbaric oxygen has been started even 36 hours after injury.⁷⁸

INTERPRETATION AND HEMODYNAMIC MONITORING

Use systolic blood pressure after the first 30 minutes of resuscitation as a decision point for further treatment. A report of EDT for blunt and penetrating trauma demonstrated a relationship between blood pressure at 30 minutes and the eventual outcome.⁷⁹ Of the 146 cases reviewed, 45 patients

(31%) were transferred to the operating room after initial resuscitation and aortic cross-clamping when necessary. For patients who survived with full neurologic recovery, the average systolic blood pressure after the first 30 minutes of resuscitation was 110 mm Hg. In those who were long-term survivors but had significant brain damage, the average systolic blood pressure was 85 mm Hg. No survivals were recorded when mean systolic blood pressure was lower than 70 mm Hg. Transfer of these patients to the operating room for definitive repair of these mortal wounds would be futile.

EDT IN CHILDREN

Trauma is the leading cause of death and morbidity in children older than 1 year.¹ Just as with adults, improved transportation of injured children to the hospital has resulted in the survival of more patients who would have been pronounced dead at the scene. Although the role of EDT has been reviewed extensively in the adult population, experience and data in the pediatric population are limited. Overall survival rates in children undergoing EDT are less than that of the adult population with one study showing an overall survival of 3% to 6%.^{80,81} This is likely as a result of a higher proportion of blunt trauma in the pediatric population. Anatomic injury patterns also showed a higher proportion of concomitant head injuries in the pediatric population. Rates of survival below age 15 are very poor. Despite poor survival rates, the general consensus is that EDT is indicated for traumatic pediatric patients with similar indications discussed earlier in this chapter.

COMPLICATIONS

A variety of significant complications occur in patients surviving EDT, but most of them are related to the primary injury rather than the thoracotomy. Techniques to avoid iatrogenic complications include noting the position of the left phrenic nerve and coronary arteries during EDT. Surprisingly, serious infections are uncommon. Patients receiving antibiotics during or immediately after the procedure have a low rate of infectious complications. Standard antibiotic regimens targeting skin flora are recommended, but should not delay the procedure.⁸² As a general rule, excessive attention to antiseptic skin preparation should be avoided because it may delay performance of the procedure.⁸³

Another potentially serious complication of EDT is injury or transmission of disease to health care workers. In an emotionally charged environment in which many clinicians are attempting to perform a lifesaving procedure under difficult conditions, it is easy for a needle, scalpel, or scissors to cause injury. Sharp ribs can cut clinicians quite easily (Fig. 18.17). The seroprevalence of human immunodeficiency virus (HIV) in US EDs is estimated to range from 2% to 6% or 9% in urban areas.⁸⁴ Tardiff and colleagues⁸⁴ noted an HIV-positive rate of 7.2% in a study of trauma patients taken to their urban ED. Occupational exposure to both hepatitis B and hepatitis C virus is also of concern to health care workers. Sloan and associates⁸⁵ found a 3.1% incidence of hepatitis B in trauma patients brought to their inner-city ED. Hepatitis C is now the most common viral hepatitis seen in health care workers since the advent of the hepatitis B vaccine. Approximately 2200 health care workers per year seroconvert after occupational exposure. The risk for

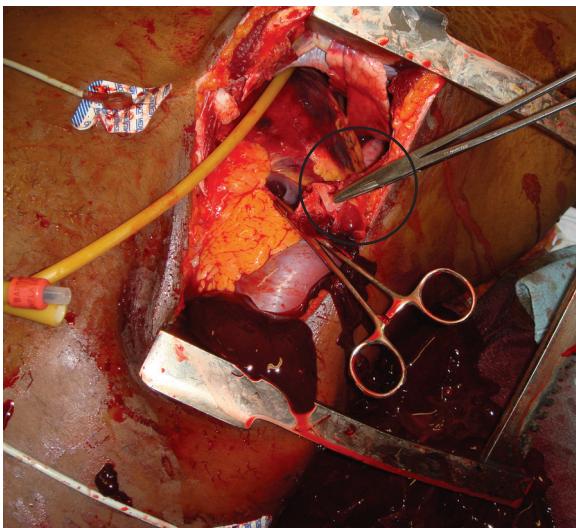


Figure 18.17 Note the sharp edges of this rib (indicated by the circled clamp), which was fractured during unsuccessful emergency department thoracotomy. The incidence of blood-borne diseases (e.g., human immunodeficiency virus, hepatitis) in trauma patients may be high and transmission to a health care worker may occur if sharp bone fragments puncture the gloves and skin.

seroconversion after occupational exposure to HIV is estimated to be 0.3% for needlestick and as high as 4.5% for deep injury.⁸⁶ Hepatitis C seroconversion rates after occupational exposure are estimated to be between 1.8% and 10%.⁸⁶ Keep the risk for exposure to staff in mind, and rigorously follow universal precautions. Although EDT must be performed rapidly to be of value to the patient, excessive haste is not warranted if it threatens the health of members of the medical team.

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352.e2 SECTION III CARDIAC PROCEDURES

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