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REVIEW

Emergency thoracotomy in thoracic trauma—a review

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Summary Thoracic trauma is one of the leading causes of death in all age groups and accounts for 25—50% of all traumatic injuries. While the majority of patients with thoracic trauma can be managed conservatively, a small but significant number requires emergency thoracotomy as part of their initial resuscitation. The procedure has been advocated for evacuation of pericardial tamponade, direct control of intrathoracic haemorrhage, control of massive air-embolism, open cardiac massage and cross-clamping of the descending aorta.

Emergency thoracotomy can be defined as thoracotomy "occurring either immediately at the site of injury, or in the emergency department or operating room as an integral part of the initial resuscitation process". Following emergency thoracotomy, the overall survival rates for penetrating thoracic trauma are around 9—12% but have been reported to be as high as 38%. The survival rate for blunt trauma is approximately 1—2%. The decision to perform emergency thoracotomy involves careful evaluation of the scientific, ethical, social and economic issues.

This article aims to provide a review of the current literature and to outline the pathophysiological features, technical manoeuvres and selective indications for emergency thoracotomy as a component of the initial resuscitation of trauma victims with thoracic injury.

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Introduction

The evolution of more efficient transport systems and improvements in pre-hospital care have increased the number of patients arriving at hospital in extremis following major trauma. Traumatic injuries still constitute one of the leading causes of death in all age groups,[56] with penetrating and blunt thoracic trauma accounting for 25—50% of all injuries,[53] as well as being a contributing cause in 50% of fatal civilian trauma.[65]

The majority of patients with thoracic trauma can be managed non-operatively, with or without tube thoracostomy.[51] As a result, careful monitoring of vital signs, appropriate fluid replacement and analgesia constitute adequate therapy in up to 90% of such patients. However, there is still a small, but significant (10—15%), subgroup of thoracic trauma victims who require emergency thoracotomy.[48,84]

Emergency thoracotomy has become an established procedure in the management of life-threatening thoracic trauma.[19,23] Indications for thoracotomy are constantly evolving and controversy still surrounds the procedure, especially in blunt trauma. Emergency thoracotomy allows evacuation of pericardial tamponade, direct control of intrathoracic haemorrhage, control of massive air-embolism, open cardiac massage and cross-clamping of the descending aorta to redistribute blood flow and limit subdiaphragmatic haemorrhage.[6,36]

Hitherto, most of the experience of this procedure has been gained in the USA and in South Africa. This article reviews the current literature and outlines the pathophysiological features, technical manoeuvres and selective indications for emergency thoracotomy, as a component of the initial resuscitation of trauma victims with thoracic injury.

Historical background

Records describing chest trauma and its treatment have survived from antiquity. An ancient Egyptian treatise, the Edwin Smith Surgical Papyrus (circa 3000—1600 BC), contains a series of trauma case reports, including thoracic injuries. One such example states: "... If thou examinest a man having a

wound in his breast, penetrating to the bone [with] perforation of the manubrium of his sternum, thou shouldst press the manubrium of his sternum with thy fingers, (although) he shudders exceedingly . . .. Thou shouldst bind it with fresh meat the first day; thou shouldst treat it afterward with grease, honey [and] lint every day, until he recovers . . .''.[20]

Homer describes thoracic wounds as early as 950 BC in The Iliad and the second century Greek physician, Claudius Galen, also noted that left ventricular injuries were the most rapidly fatal of all cardiac injuries.[33] While severe chest injuries were generally considered to be fatal during the times of the ancient Greeks and Romans, special attention was rarely paid to them, even into the modern era of warfare.

John Hunter, serving as an Army surgeon in 1761, remarked that while little had been done for victims of significant thoracic trauma, something probably could be accomplished for the good of the patient. His only contribution, however, was the tentative suggestion that a haemothorax might be treated by allowing the fluid to run out of the wound.

Baron Dominique-Jean Larrey, Napoleon's surgeon and the early developer of the triage system, made similar recommendations concerning thoracic injuries in 1829.[8] Otto Hoche wrote in 1940 that of the 11 million wounds, sustained by soldiers of the armies of Great Britain, the United States, France and Germany in World War I, there were 660,000 wounds of the chest (6% of all wounds), of which 56% were fatal. Hoche's collected figures also show that of 12,350 soldiers killed in action, 20% had chest wounds.[42] It was not until World War II that guidelines were established for treating thoracic injuries; the understanding and treatment of thoracic injury advanced dramatically during the Vietnam War era.

The concept of thoracotomy as a resuscitative measure began with Schiff's promotion of open cardiac massage in 1874. This was followed by Block's suggestion in 1882 that thoracotomy be applied in the repair of cardiac lacerations. Two decades passed before Ludwig Rehn successfully sutured a right ventricular wound in a human.[67] Only at the start of the 20th century did emergency thoracotomy begin to come into routine use for the treatment of cardiac wounds and anaesthesia-induced cardiac arrest.[9]

In the succeeding century, a more selective approach to emergency thoracotomy evolved, as alternative procedures have become established, not least the advocacy of closed chest compression by Kouwenhoven et al. in 1960, which virtually eliminated the need for open cardiac resuscitation.[49] In 1967, Beall et al. aroused interest in emergency room thoracotomy in moribund patients with penetrating chest trauma.[5] Following this, literature relating to emergency thoracotomy, in the early 1970's, specifically addressed three basic issues:

Why should emergency thoracotomy be performed?
Where should it be performed?
When is it (or, perhaps more importantly, when is it not) appropriate to perform thoracotomy?

While the first two issues were considered early, in a flurry of research activity, the third issue still remains controversial; most clinicians agree that the question is related to the ability to predict outcome following thoracic trauma.[19]

Definitions of emergency thoracotomy

There are numerous different terms for emergency thoracotomy. These depend on the circumstances in which the procedure is performed, the status of the patient and the location of the procedure itself. Examples include emergency department thoracotomy, emergent thoracotomy, early thoracotomy, resuscitative thoracotomy, etc. This can make interpretation of the available data and comparison of studies difficult, due to the use of the terms interchangeably. In general, emergency thoracotomy can be undertaken at any stage of the resuscitative process, and so can be defined in terms of the urgency of the procedure in relation to the patients' physiological status.

Thereby, emergency thoracotomy may be defined as that occurring either immediately at the site of injury, in the emergency department, or in the operating room, as an integral part of the initial resuscitation. An urgent thoracotomy is one that takes place under more controlled circumstances and in the context of appropriate physiological stability and hitherto successful resuscitation. Lastly, an elective (or formal) thoracotomy one that is performed during the course of elective surgical access to the thorax, such as for coronary artery bypass surgery.

Pathophysiology of thoracic trauma

The incidence and causes of thoracic trauma vary widely in different parts of the world. Thoracic trauma ranks third behind head and extremity trauma in major accidents in the United States, with motor vehicle accidents being the most common aetiology.[53] In large, American cities and parts of South Africa, black males have a 1 in 20 chance of

Table 1 Major causes of thoracic injury in Europe [87]

Mechanism	Proportion (%)
Road traffic accident	60
Industrial accidents	15
Domestic incidents	10
Sporting injuries	10
Interpersonal conflict or suicide	5

being fatally stabbed, or shot, before the age of 30.[23] Experience in the UK is more limited, with reports containing higher proportions of patients with blunt injuries.[72] Table 1 shows the relative causes of thoracic trauma in Europe. In England and Wales, the annual death rate from stabbing and gunshot wounds is fewer than 200, although rising. Nevertheless, the figures are increasing for all casualties from road traffic accidents, with more than 60,000 admissions per year.[87] In motorcycle accidents, 75% of fatally injured riders had an injury to the thoracic region, compared to 20% of non-fatally injured riders.[50] Along with head trauma, thoracic injuries are also a major cause of death in pedestrians involved in road traffic accidents.[43]

The main consequences of chest trauma occur as a direct result of its combined effects on respiratory and haemodynamic functions. Death following thoracic injury is often secondary to impairment of oxygen delivery and/or transport. Factors determining oxygen transport capacity include pulmonary gas exchange, cardiac output, haemoglobin concentration and oxygen—haemoglobin affinity.

Several compensatory mechanisms exist in response to the physiological changes resulting from thoracic trauma, although these can be rapidly exhausted. The therapeutic goal is to augment, or supplement, these compensatory mechanisms dur-

ing acute resuscitation, the major two interventions being ventilatory support and the arrest of haemorrhage (including surgical repair of cardiovascular disruptions). Impairment of oxygen transport mechanisms and the resultant hypoxia can also contribute to other primary causes of mortality, particularly brain injury. Figs. 1 and 2 illustrate the physiological processes that occur as a result of thoracic trauma.[69,81]

Blunt thoracic trauma is almost exclusively the result of rapid deceleration, or crushing, in road traffic accidents. The most common intra-thoracic injuries sustained following blunt trauma are haemothorax, great vessel disruption and lung contusion.[47] Injuries resulting from blunt trauma can be predicted from knowledge of the type of incident, as shown in Table 2.[87] Newman and Jones showed that unrestrained drivers have a higher incidence of rib fractures and corresponding intrathoracic injuries for frontal and rollover mechanisms than do restrained drivers.[64] However, restraint seemed to confer no real advantages with side impact. Severity of injury was also shown to be directly related to impact velocity, with significant injury commonly occurring at impact speeds of around 10—20 mph in unrestrained persons, compared to at least 30 mph in restrained individuals.[64] Severity of thoracic injury can be predicted from the type of impact, speed of impact and adequacy of restraint.

During sudden profound deceleration, the heart swings on the aorta, tearing the great vessels—the so-called intrathoracic 'bell clanger' effect. This commonly occurs at the ligamentous attachment of the descending aorta to the left pulmonary artery. Shear forces may also disrupt the bronchi, leading to immediate pneumothorax and not infrequently tension or 'massive' pneumothorax, which
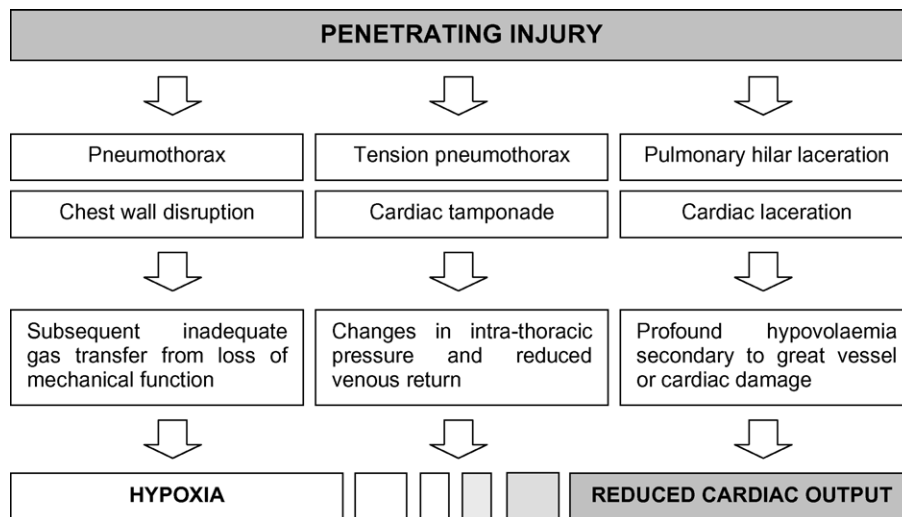

Figure 1 Summary of the pathophysiological consequences of penetrating thoracic trauma.
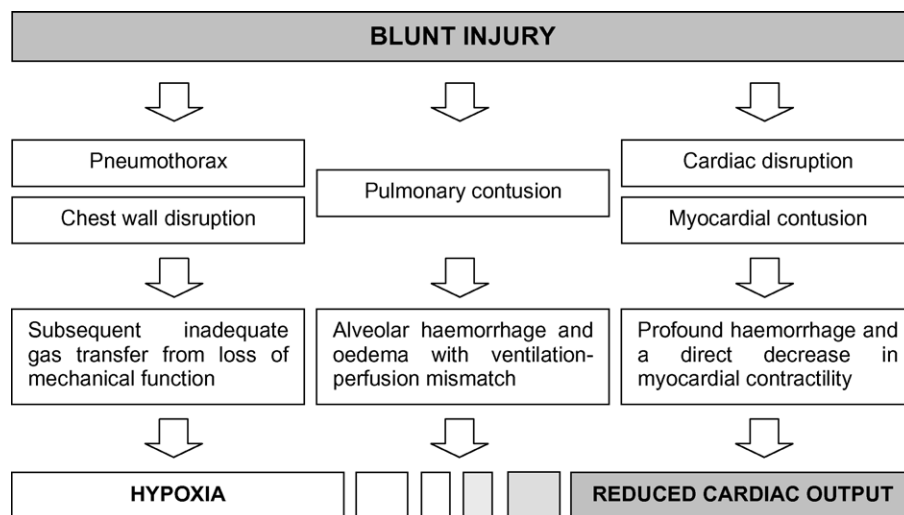
Figure 2 Summary of the pathophysiological consequences of blunt thoracic trauma.

may be challenging to manage with simple chest drainage alone. Crush injury compresses the myocardium between the sternum and the vertebrae, resulting in contusion, or rupture, of the myocardium and possible great vessel disruption. Sudden severe crush injury of the abdomen and extremities may also cause a dramatic increase in intrathoracic venous pressures, leading to right atrial, or ventricular, rupture. Cardiac valve injuries occur as a consequence of shearing, or crushing, forces to the heart and can easily be overlooked.

Penetrating trauma results in localised anatomical disruption, significantly to blood vessels, depending on the location and angle of entry and the type of object, or projectile, involved. In penetrating ballistic trauma, the track of the projectile may be erratic and very difficult to predict, despite obvious entry and exit wounds. High velocity transfer projectiles may produce far more profound tissue damage, due to laceration and cavitation, and

few victims survive high velocity wounds to the heart, great vessels, or pulmonary hila.

The major physiological consequence of penetrating trauma is usually haemorrhage. Arterial bleeding is often rapid, although vessel retraction and vasoconstriction can arrest haemorrhage. Venous bleeding may be arrested by tamponade, as intravenous pressure falls. Laceration to the myocardium, or coronary vessels, may lead to pericardial tamponade, most often occurring with a mediastinal entry site.[87] Penetrating thoracic trauma generally results in an open pneumothorax. When the chest wound is smaller in diameter than the glottis, the pneumothorax is usually small and pulmonary ventilation is preserved. However, when the wound is larger in diameter than the glottis, the pneumothorax will increase due to preferential air passage through the chest wall defect.

Direct communication may occur between blood vessels and air passages, or lung parenchyma, sec-

Table 2 Mechanisms and patterns of blunt thoracic trauma[87]

Mechanism of injury	Chest wall injury	Possible thoracic visceral injuries	Common associated injuries
High velocity (deceleration)	Chest wall often intact ± sternum fracture ± bilateral rib fractures with anterior flail	Ruptured aorta; cardiac contusion; tracheo-bronchial disruption; ruptured diaphragm	Head and Max-Fax injuries; C-spine fracture; lacerated liver/spleen; long bone fractures
Low velocity (direct blow)	Lateral: unilateral rib fractures; anterior: fractured sternum	Pulmonary contusion; cardiac contusion	Lacerated liver/spleen if lower ribs involved Max-Fax injuries
Crush injury	Anteroposterior: bilateral rib fractures ± anterior flail; lateral: ipsilateral fractures ± flail; possible contralateral fractures	Ruptured bronchus; cardiac contusion; pulmonary contusion	Fractured thoracic spine; lacerated liver/spleen; lacerated liver/spleen

ondary to trauma involving these structures. Systemic air embolism will occur if air enters pulmonary veins as a result of low pulmonary venous pressure, increased airways pressure, or both. The consequences may be catastrophic if pulmonary venous gas embolises to the coronary vessels, heart chambers or cerebral arteries. The incidence of systemic air embolism has been estimated to be 4–14%, with two thirds resulting from penetrating injury and one third from blunt trauma.[80,88]

Haemorrhage

Bleeding may be obvious if it reaches the exterior, especially in penetrating trauma. Death from exsanguination is not just limited to penetrating thoracic trauma. Bodai et al. noted that, in their series of 38 patients undergoing emergency thoracotomy for blunt trauma, 19 (50%) deaths could be attributed to massive haemorrhage.[12] The only sign of severe intrathoracic haemorrhage may be the clinical features of shock, including restlessness, agitation, tachycardia, sweating, pallor and peripheral venospasm, with reduced capillary circulation. Signs of shock may be apparent with respiratory distress, as well as with significant haemorrhage. The volume of blood lost into the pleural cavity is difficult to assess without drainage by tube thorocostomy. Each hemithorax can rapidly accommodate more than half of a patient's total blood volume before physical signs become obvious.[9]

The question of when to perform a chest radiograph is also controversial. Bokhari et al. demonstrated that in blunt trauma, patients who are haemodynamically stable, with normal physical findings on examination, do not require a routine chest radiograph. By contrast, they found that all victims of penetrating trauma require chest radiographs, because many will have haemopneumothorax without overt clinical findings.[15] For unstable patients with physical findings of thoracic trauma, immediate treatment is required, such as needle thoracostomy for tension pneumothorax, and careful physical examination to elucidate a significant haemothorax.

Tube thoracostomy drainage serves to relieve dyspnoea and to improve gas transfer and ventilation/perfusion mismatch, as well as identify continued bleeding and the need for thoracotomy. It has been suggested that surgical exploration is indicated when initial drain insertion yields more than 1500 ml of blood, or if the rate of drainage is more than 250 ml/h.[84] However, the response to fluid resuscitation, the nature of the trauma (blunt versus penetrating) and, if available, specialist advice must also be taken into account.

Pericardial tamponade

The presentation of pericardial tamponade depends on the underlying cause. Myocardial rupture, or coronary artery laceration, will result in the abrupt appearance of tamponade, while minor lacerations, or contusions, with slow extravasation result in a gradual rise in intrapericardial pressure. This clinical appearance may well be confused with pulmonary embolism in the early stages, due to its effects on diastolic right atrioventricular filling.[81]

Often, patients with penetrating cardiac wounds reaching hospital alive do so because of the arrest of bleeding by pericardial tamponade. The combination of a praecordial entrance wound with profound systemic hypotension, tachycardia and distended neck veins is pathognomonic.

Elevated intrapericardial pressure restricts cardiac filling, thereby leading to diminished cardiac output.[86] Cardiac arrest occurs later due to coronary hypoperfusion, as the intrapericardial pressure approaches ventricular filling pressure. In the early stages of pericardial tamponade, blood pressure may be maintained deceptively well, complicated by the fact that aggressive fluid resuscitation will temporarily elevate filling pressures and overcome, to an extent, the effect of the tamponade. However, clinical signs of systemic shock will soon become apparent. In the later stages of tamponade, precipitous and profound hypotension occurs as the physiological compensatory mechanisms fail.[75,85]

Systemic air embolism

Despite being a subtle clinical entity, systemic air embolus should be considered in any major thoracic injury resulting from either penetrating or blunt trauma. It is often diagnosed only when sudden circulatory collapse occurs immediately after tracheal intubation and the initiation of positive pressure ventilation. This collapse is typically unresponsive to conventional resuscitation. The unexplained development of a neurological deficit, or seizures, in the absence of a head injury implies cerebral air embolism unless proven otherwise.[81]

The current recommendation for treatment of systemic air embolus associated, with unilateral lung injury, is immediate thoracotomy, in the emergency department if necessary, in order to clamp the hilum of the injured lung so as to arrest the passage of air into the systemic circulation.[88] Bubbles may be noted in the vasculature on thoracotomy. Selective ventilation of the uninjured lung may be a life-saving alternative procedure in unilateral injuries.[41] Saada et al. demonstrated that there is

an observed decrease in emboli when ventilatory pressures and volumes are reduced.[71]

Junctional trauma

Blunt trauma rarely presents with thoracic injury in isolation. It often involves the so-called 'junctional zones', above and below the anatomically defined boundaries of the thorax. Such zones include the root of the neck, the thoracic spine and the upper abdomen/diaphragm. When there is suspicion of an abdominal cause for haemorrhage it has been recommended that the patient undergo laparatomy before thoracotomy, given both the vulnerability of abdominal viscera to blunt trauma and early availability of appropriate surgical expertise.

Junctional zones may also be implicated in penetrating thoracic trauma. Projectiles and other objects may enter the thorax from below, via the abdominal cavity (through the diaphragm), from above via the neck, or through the thoracic spine. As a result, intrathoracic injury may not be suspected initially due to the more distant location of the entrance wound. However, significant thoracic trauma should always be considered in the case of junctional zone trauma, especially when the clinical signs cannot be explained by the expected mechanism of injury. Associated diaphragmatic rupture can also complicate the clinical presentation; the combination of abdominal visceral rupture and a diaphragmatic tear may lead to apparently excessive drainage from a thoracostomy tube. Although the volume of such drainage may suggest the presence of significant intrathoracic trauma, an initial thoracotomy may be relatively unhelpful and, if anything, delay the necessary laparotomy.

Physiological status at presentation

The physiological status of the patient will affect clinical decision-making with respect to emergency thoracotomy. Survival rates are directly correlated with the patient's physiological status in the pre-hospital and hospital setting.[26,54,68] Henderson et al. demonstrated that the physiological index was the most significant independent factor predicting patient survival following emergency thoracotomy.[40] Importantly, exclusion criteria for the procedure, in many guidelines and recommendations, include the absence of 'signs of life'. Therefore, an accurate and reproducible categorisation of physiological status is required. Table 3 shows a modified version of the classification recommended by Lorenz et al.

Hospital clinicians vary greatly in their definition of 'signs of life'. Miglietta et al. showed that a palpable pulse and spontaneous movements were the most commonly acknowledged, though even the more straightforward indicators (such as pupillary reflex and electrical cardiac activity) were far from uniformly agreed.[62] Emphasis is needed on clearly defining the physiological status of the patient, ideally at scene and/or in transit. However, the problems of deciding on the presence, or absence, of signs of life are even more difficult in a pre-hospital setting.

Prognosis following thoracic trauma

In patients presenting with vital signs after a penetrating thoracic injury, survival from emergency thoracotomy may be as high as 38%.[4] The American College of Surgeons Committee on Trauma carried out a major review of the literature from 1966 to 1999, in order to evaluate the many reports dealing with emergency department thoracotomy.[1] A strict selection was carried out and 92 articles were referenced. Sixty-three were based on retrospectively collected data, while 29 were clinical studies, only 3 of which were prospective. They reported that of 7035 emergency thoracotomies there were a total of 551 survivors (7.8%). Stratification by mechanism of injury revealed a survival rate of 11.2% for penetrating trauma and 1.6% for blunt trauma. Importantly, of

Table 3 Physiological status classification[54]			
Class I: no signs of life	Class II: agonal	Class III: profound shock	Class IV: mild shock
No electrical activity: described as asystole or ventricular standstill.	Electromechanical dissociation (EMD) or pulseless electrical activity (PEA)	Systolic blood pressure less than 60 mmHg	Systolic blood pressure between 60 and 90 mmHg
Absent pupillary, corneal and gag reflexes	Any electrical activity on ECG without palpable pulse or	Transient responder or unresponsive to fluid	Stable response to fluid resuscitation
GCS 3	measurable blood pressure	resuscitation	

14 series reporting accurately on neurological outcomes, 4520 patients underwent emergency thoracotomy with a survival rate of 226 (5%) and of these 34 (15%) survived with neurological impairment. Penetrating cardiac injuries were shown to have the highest survival rate with 46 series (1165 cases) yielding an overall survival rate of 31.1% following emergency thoracotomy.

It has already been shown that physiological status correlates well with survival rate. In an analysis of 251 cases of cardiac injury following emergency thoracotomy, Henderson et al. showed that survival rates diminished significantly with higher physiological indices: the overall survival rate in this study was 18.7%. The findings suggested that emergency thoracotomy is most helpful for patients with limited penetrating cardiac injuries who have significant physiological impairment secondary to pericardial tamponade.[40]

Significant differences in survival rates following emergency thoracotomy are noted when comparing blunt and penetrating thoracic trauma. Over the past few decades a number of studies has shown no survival in cases of blunt trauma.[12,36,44] In their review, Biffl et al. showed that an overall survival rate following emergency department thoracotomy in blunt thoracic trauma is 1.1%, compared to 9.1% for penetrating cardiac trauma.[9]

Indications and contraindications for emergency thoracotomy

The major difficulty with attempting to standardise the indications for emergency thoracotomy is that the main body of evidence in the literature is largely derived from retrospective data. Emergency thoracotomy is not a procedure that lends itself to randomised, prospective trials and hence it remains a highly controversial procedure. There is also significant variation in nomenclature of emergency thoracotomy in the available literature, making statistical analysis and comparisons

between relevant studies difficult. In this review, the definition of emergency thoracotomy is, as previously discussed, that which is required as part of the immediate resuscitation of the trauma patient.

It is first of all important to discuss the clinical grounds and theoretical justifications for performing a thoracotomy. The primary physiological objectives of emergency thoracotomy are listed in Table 4.

Since its introduction into clinical practice, the recommended indications for emergency thoracotomy have become increasingly selective. ATLS guidelines offer specific recommendations for carrying out thoracotomy in the setting of penetrating chest trauma with electrical cardiac activity, but not for blunt trauma with electrical cardiac activity in a pulseless patient. Other indications, such as penetrating abdominal, or extremity, trauma, are not addressed. Several studies have concluded that there is no value in performing emergency thoracotomy in moribund patients with blunt trauma.[13,22,54,61] The primary indication for thoracotomy is generally accepted to be a penetrating injury of the thorax in patients on the point of arresting, or who have just arrested, or in those who are in profound shock.[65] Brown et al. concluded that emergency thoracotomy should be limited to patients with penetrating thoracic trauma with signs of life, a pulse and measurable blood pressure. They also concluded that patients with no signs of life, or an agonal physiological status, do not survive emergency thoracotomy and that, therefore, the use of this procedure in these patients should be abandoned.[22]

Bleetman et al. noted in their series of 25 patients, in a UK Accident & Emergency Department, that the best results were seen in those patients stable enough to undergo thoracotomy in the operating theatre. Of the 18 emergency room thoracotomies, only 1 survived to discharge, while all 7 of the operating department thoracotomy patients survived to discharge. It was noted,

Table 4 The physiological rationale for emergency thoracotomy	
Procedure	Physiological benefit
Release of pericardial tamponade	Improve cardiac output and control of cardiac haemorrhage
Control of intrathoracic vascular or cardiac haemorrhage	Facilitate fluid resuscitation—'turning off the tap'. Improve cardiac output and myocardial perfusion
Control of massive air embolism or bronchopleural fistula	Resolve myocardial ischaemia and hence myocardial contractility as well as prevent neurological injury
Permit open cardiac massage	Improved resuscitative cardiac output and coronary perfusion especially with limited ventricular filling pressures
Occlusion of descending aorta (cross-clamping)	Redistribution of limited blood volume to myocardium and brain as well as limiting subdiaphragmatic losses.

however, that the majority of patients who underwent emergency department, rather than operating room, thoracotomy had the worst survival probabilities of the series.[11] Balkan et al. also noted improved survival rates amongst those undergoing operating room emergency thoracotomy, accepting that a stable physiological status was the significant factor.[3]

In a careful review of the literature, Danne et al. noted that in most cases blunt trauma to the thorax resulted in very poor survival after emergency department thoracotomy, while penetrating thoracic wounds were associated with the best survival rates following the procedure. Importantly, it was shown that all survivors in the study had some vital signs at the scene.[27] Isolated reports exist in which groups of patients with blunt thoracic trauma had high survival rates after emergency thoracotomy.[38,58] However, the authors noted that these cases could have been explained by differences in patient selection, criteria, or physiological status, on admission and it was also noted that the determination of 'survival' was not consistent across articles.

Kish et al. noted that the majority of emergency thoracotomies performed in their series were undertaken for haemorrhage as a result of penetrating trauma, manifest either as direct external losses via thoracostomy tube, or indirectly by noting physiological changes and fluid resuscitation demands. Survival in this group was significantly higher than for blunt trauma. However, they noted that patients sustaining blunt trauma commonly had extensive multiple system injuries and other sources of haemorrhage.[48]

Lewis and Knottenbelt, in a series of 45 cases, suggested that the primary indication for resuscitative emergency thoracotomy was an observable pericardial tamponade, and that results were shown to be good for this single indication. However, they noted that emergency thoracotomy was justifiable for all patients with cardiac arrest, or persisting severe hypotension, following penetrating thoracic trauma, as not all cases of tamponade are clinically obvious on admission. They also concluded that the case for emergency thoracotomy in blunt trauma remained debatable.[52] In a detailed literature review, the American College of Surgeons Committee on Trauma recommended that emergency thoracotomy be performed rarely in blunt thoracic trauma with cardiopulmonary arrest, due to low survival rates and poor neurological outcomes.[1] Grove et al. repeated these conclusions, reporting no survivors at all from a total of 19 cases, over a 2-year period, of blunt multisystem trauma, including thoracic injury requiring emergency thoracotomy.[36]

Miglietta et al. assessed the opinions and attitudes of trauma specialists in America, demonstrating a wide variety of indications for emergency thoracotomy over a diverse selection of clinical scenarios in many different institutions. Most of the reported indications were liberal, especially for blunt trauma scenarios. However, in the main, indications were determined by clinical parameters, such as the existence of signs of life and the mechanism of injury, rather than physician associated, or institutional, factors.[62]

As discussed previously, wide variation exists in the definition of signs of life, which, in turn, has a notable effect on uniformity and selectivity for emergency thoracotomy in different institutions. Generally, however, most respondents agreed that emergency thoracotomy was more appropriate in the setting of penetrating thoracic trauma than other mechanisms.

Cardiopulmonary arrest 'in transit', or in the pre-hospital setting, is almost uniformly fatal following trauma.[36] Such patients arriving in the emergency department in asystole invariably die, despite all resuscitative attempts.[29,38] Emergency thoracotomy in these cases is not considered to be an appropriate procedure.

When considering the definitive indications for emergency thoracotomy, the decision to proceed depends greatly on many local circumstances, including availability and preparedness of correct surgical equipment and trained personnel, departmental policies and protocols, and the experience of the unit in carrying out the procedure. The indications and contraindications set out in Table 5 have been summarised on the basis of the available published evidence. These may serve as a guide on which to base local policy and protocols, taking into account those factors discussed above.

Whilst physiological status is held to be the most appropriate indication for performing emergency thoracotomy, most authors also recommend that the specific application of any guidelines must, where possible, include consideration of the individual patient's circumstances, such as age, quality of life, or pre-existing disease. In addition, logistical issues, such as availability of specialist personnel and accessibility, and proximity to appropriate operating facilities and equipment, should also be considered.

Emergency thoracotomy in children

Trauma is the leading cause of death and morbidity in children over 1 year of age.[37] The majority of paediatric trauma patients who require emergency

Table 5 Suggested indications and contraindications for emergency thoracotomy

Indications	Relative indications	Contraindications
Cardiorespiratory arrest following isolated penetrating thoracic trauma, with evidence of signs of life before arrival in emergency department	Post traumatic refractory hypotension, transiently responsive with evidence of intrathoracic haemorrhage	Absence of signs of life or patient in asystole on arrival in the emergency department, following blunt thoracic trauma
Post traumatic persistent hypotension due to intrathoracic haemorrhage, unresponsive to fluid resuscitation	Post traumatic persistent hypotension, due to extrathoracic haemorrhage unresponsive, or transiently responsive to fluid resuscitation	Absence of signs of life at scene and on arrival, following cardiopulmonary resuscitation for more than 5 min
Persistent severe hypotension, with evidence of systemic air embolism or pericardial tamponade	Presence of signs of life on arrival in emergency department, independent of mechanism	Associated severe head injury or thoracic injury as part of severe multisystem trauma

thoracotomy do so following blunt trauma and usually have sustained multisystem injuries.[35] Just as in adult trauma, improved transportation of injured children to hospital has resulted in the arrival and treatment of patients who may otherwise have been pronounced dead at the scene. Standardisation and regionalisation of the trauma care of children have led to new problems, including the need to define the role of emergency resuscitative thoracotomy in injured children, otherwise unresponsive to conventional resuscitation.

Although the role of emergency thoracotomy has been reviewed extensively in the adult literature, there are comparatively little experience and data for paediatric cases. Anecdotal reports and the impression that children may tolerate more readily ischaemia and the physiological stress of severe trauma, have led to the expectation that aggressive resuscitation, including thoracotomy, should have an improved outcome in this group of patients.[30] As a result, selection criteria for emergency thoracotomy in children are uncommon in most centres, including those which have defined protocols for adult thoracotomy.

Unfortunately, the hope that children may have a more favourable outcome than adults following emergency thoracotomy, has not been borne out by published evidence. Although there is limited experience with emergency thoracotomy in children, comparison of adult and paediatric survival rates show remarkable similarities. Overall survival rates in children following emergency thoracotomy for penetrating thoracic trauma are around 11–12% and for blunt trauma around 1–2%.[1,9] Again, the highest survival rates were noted in cases of thoracotomy following single penetrating wounds to the thorax.

As in adults, the data support the selective application of emergency thoracotomy in children based on injury mechanism and physiological status at presentation. General consensus is derived from recent literature that the indications for emergency thoracotomy in children should be the same as those currently accepted for adult trauma victims.[7,70,74]

Pre-hospital care considerations

In their study, Sugg et al. found that <20% of patients with penetrating wounds of the heart reached hospital alive.[78] Presently, with improved emergency transport systems, more patients are being seen in emergency departments for treatment following thoracic trauma. The chances of survival are greater if time from injury to definitive surgery is kept to a minimum. Survival rates after emergency department thoracotomy have been correlated with field and transport times.[24] Survival from penetrating thoracic trauma has been shown to decrease sharply if patients reach hospital more than 25 min after injury.[34] Branas et al. showed that there was no observed effect on patient survival as a result of the use of non-medical personnel to transport trauma patients to hospital. This offered further support to the concept of 'scoop and run', although it is possible that a confounding factor is introduced by at-scene triage by attending crews.[18] Minimizing the use of field stabilisation manoeuvres has also been shown to improve survival of critically injured patients.[77]

On-scene thoracotomy

Experience of on-scene thoracotomies has lead to the abandonment of this practice by some.[66] It is noted that the best outcomes are achieved in patients who have signs of life at the scene and

Table 6 Guidelines for carrying out prehospital thoracotomy[25]
Evidence of penetrating thoracic trauma
Patient is found to lose pulse at scene
Patient is to be intubated immediately
Nearest surgical intervention is:

More than 10 min away (following loss of pulse)	**Less** than 10 min away (following loss of pulse)
On-scene thoracotomy	**Immediate transport**

reach hospital within 10 min of injury.[34] The limited efficacy of on-scene thoracotomy tends to support a 'scoop and run' policy, as delay due to the procedure may be detrimental to the overall management of the patient. Also, it is far more advantageous to carry out the procedure with a trained, multi-disciplinary team using suitable facilities and equipment. A solo doctor attempting the procedure at the scene may additionally be required to maintain a difficult airway, or provide assistance to other trauma victims. However, a few series have been published which show benefit to some patients following prehospital thoracotomy, most notably the results from the London Helicopter Emergency Medical Service (HEMS). In their series of 39 cases, there were 4 survivors (10%), 1 with long-term disability. The conclusion of the team is that prehospital thoracotomy should be considered if there is an appro-

priately experienced, trained and equipped doctor present, who is acting within a trauma system with continuing training and quality assurance. The guidelines used by the HEMS team are shown in Table 6.[25] In their case report and review of pre-hospital thoracotomy, Wall et al. suggested a similar decision-making process.[83]

Other measures

In the study by Durham et al. the duration of pre-hospital cardio-pulmonary resuscitation (CPR) before thoracotomy was evaluated as a prognostic factor. A significant difference was noted between survivors and non-survivors with the data suggesting that 5 min of prehospital CPR approaches the limits of viability in non-intubated patients. However, the
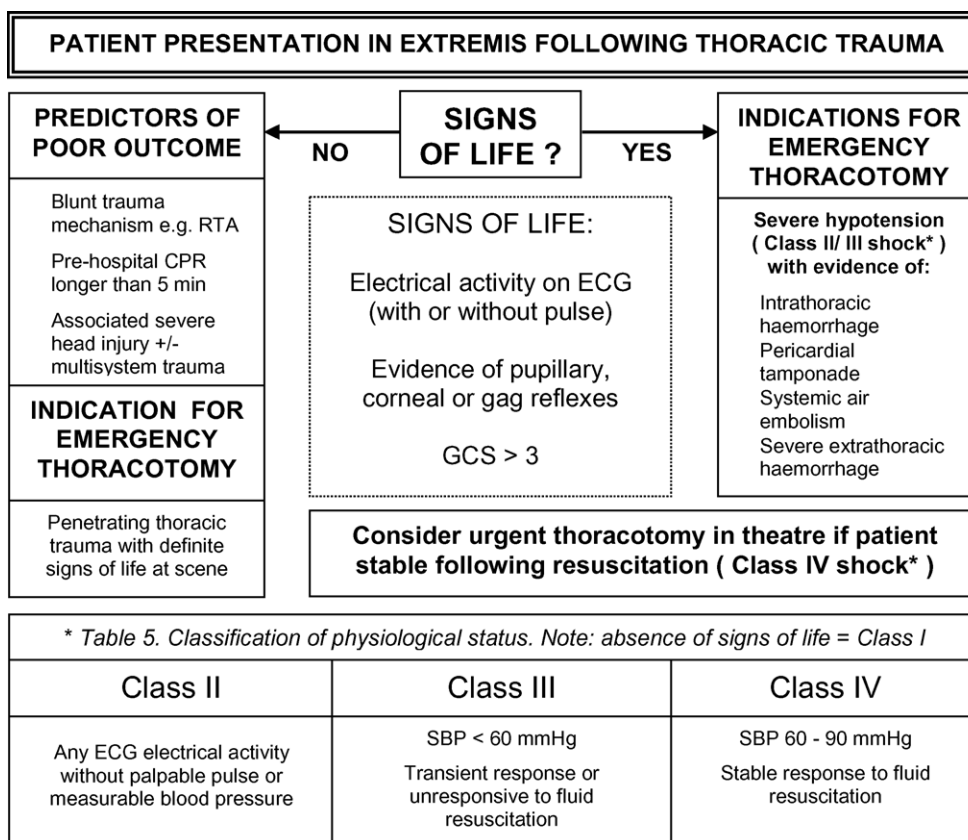

PATIENT PRESENTATION IN EXTREMIS FOLLOWING THORACIC TRAUMA

PREDICTORS OF POOR OUTCOME ← **NO** **SIGNS OF LIFE ?** **YES** → **INDICATIONS FOR EMERGENCY THORACOTOMY**

Blunt trauma mechanism e.g. RTA

Pre-hospital CPR longer than 5 min

Associated severe head injury +/- multisystem trauma

INDICATION FOR EMERGENCY THORACOTOMY

Penetrating thoracic trauma with definite signs of life at scene

SIGNS OF LIFE:

Electrical activity on ECG (with or without pulse)

Evidence of pupillary, corneal or gag reflexes

GCS > 3

Consider urgent thoracotomy in theatre if patient stable following resuscitation (Class IV shock*)

Severe hypotension (Class II/ III shock*) with evidence of:

Intrathoracic haemorrhage
Pericardial tamponade
Systemic air embolism
Severe extrathoracic haemorrhage

* Table 5. Classification of physiological status. Note: absence of signs of life = Class I		
Class II	Class III	Class IV
Any ECG electrical activity without palpable pulse or measurable blood pressure	SBP < 60 mmHg Transient response or unresponsive to fluid resuscitation	SBP 60 - 90 mmHg Stable response to fluid resuscitation

Figure 3 Decision making process flowchart for emergency thoracotomy.

average time of CPR tolerated by intubated survivors was shown to be doubled, compared to non-intubated survivors (9.4 min versus 4.2 min).[29] It is therefore essential to record accurate information relating to prehospital resuscitation efforts, so that the decision to carry out emergency thoracotomy can be made appropriately, once the patient arrives in the emergency department.

Protocols

Several studies, original articles and reviews suggest protocols, or decision-making flow charts, for emergency thoracotomy.[9,10,17,36,82] These, and the general recommendations found in the related literature, vary in their complexity and differ in their suggested indications and contraindications. Most of the guidelines rely on a mixture of general physiological observations and observer information regarding mechanism of injury and response to initial resuscitation. One of the major issues regarding protocols is that while proscriptive, or highly selective, guidelines may result in improved survival rates from emergency thoracotomy, the risk is that a potentially salvageable patient may be excluded.

A comprehensive protocol that includes specific physiological indicators and consideration of the mechanism of injury, as well as relevant associated clinical factors, such as age and secondary trauma, may prove to be a useful tool when considering performing emergency thoracotomy. However, this is unlikely to be of practical use when dealing with such a critically ill patient. Fig. 3 aims to summarise the current evidence utilising a simple flowchart as a guide for the decision-making process. The main elements of this are the presence or absence of life signs on presentation and the major secondary prognostic indicators associated with highest survival rates, or, conversely, those associated with a generally poor outcome.

Technique of thoracotomy and adjunct manoeuvres

Equipment

For a formal (elective) thoracotomy the range of equipment and number of instruments is far in excess of that required for emergency thoracotomy. Table 7 illustrates the typical emergency thoracotomy instrument list.[9,14,21]

Approach and access to the thorax

Ideally, venous and arterial access should be established before thoracotomy is performed. However, excessive time should not be wasted on this as venous and arterial access can be obtained rapidly once the thorax is open; potential sites including direct insertion into the right atrium, or superior vena cava. Arterial cannulae may also be placed directly into the aorta, or left ventricle, for pressure monitoring. The patient should be positioned supine, with the side to be operated on elevated slightly (about 15°) by a wedge, or pillow. Both arms should be laid out at right angles to enable peripheral vascular access. Surgical draping is not essential for resuscitative thoracotomy.

Arguably, the best incision for use in emergency thoracotomy should be determined on the basis of the anticipated injury, as suggested by the clinical examination. The left anterolateral thoracotomy is

Table 7 Instrument and equipment list for emergency thoracotomy

Instrument	Role/comments
Scalpel—no. 10 blade	Incision of skin and soft tissues
Suitable retractor, such as Finochietto's rib spreader, or Balfour abdominal retractor	Opening up the rib space
Lebschke's knife and mallet, or Gigli saw	Cutting through sternum
Curved Mayo's scissors	General dissection
Toothed forceps	Exploration and suturing
Large vascular clamps, such as Satinsky	Major vessel haemorrhage
DeBakey aortic clamp	Aortic cross-clamping
Mosquito/Dunhill artery forceps	Haemorrhage control
Foley catheter	Temporary cardiac wound seal
Long and short needle holders	Suturing/placing ties
Internal defibrillator paddles	Intrathoracic defibrillation
Sutures, Teflon pledgets, sternal wires	To include 3/0 non-absorbable sutures and 2/0 absorbable ties
Skin preparation materials and swabs	For example, a laparotomy pack
Good lighting and high volume suction	Essential both in- and pre-hospital

frequently utilised for resuscitation and in acute deterioration, or cardiac arrest.[32] The advantages of this incision are rapid access with simple instrumentation, its appropriateness for a supine patient, and easy extension to the contralateral hemithorax with exposure of pleural, anterior and mediastinal structures.[9] This approach also allows for aortic cross-clamping and open cardiac massage. In isolation, however, it affords relatively limited access, particularly for injuries to the heart, lungs or great vessels necessitating direct surgical repair. It can be argued that this is best regarded as an initial approach, facilitating the relief of cardiac tamponade, or enabling massage, prior to extension into a bilateral anterior thoracotomy (clamshell incision) which, although an aggressive approach, facilitates access to pleural and pericardial cavities, as well as extension into the neck or abdomen.

An initial right anterolateral incision should be reserved for cases involving penetrating injuries to the right side of the chest. When an associated cardiac wound is noted, or further resuscitative measures are required, this incision should be extended trans-sternally. A median sternotomy allows for exposure of the anterior and middle mediastinum and is advocated particularly for penetrating wounds of the upper anterior thorax, but, in the emergency setting, its applicability is typically limited by the availability of the equipment required to divide the sternum longitudinally. Its applicability is also questionable for injuries involving the lungs, or pulmonary hila.

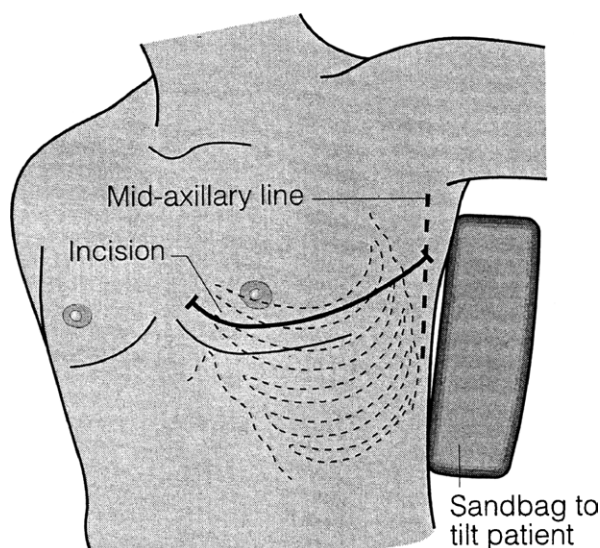The left anterolateral thoracotomy is made in the 5th or 6th intercostal space, starting from the costochondral junction anteriorly and passing to the mid-axillary line laterally, following the upper border of the rib (Figure 4). In women, the breast will need to be retracted superiorly to expose this interspace and the infra-mammary fold may be used as a guideline. The skin and subcutaneous layer are first incised with a scalpel and then the muscle, periosteum and parietal pleura are divided in one layer with scissors and blunt dissection. Chest wall bleeding is generally minimal in these patients, though the internal thoracic arteries will need to be ligated. Once the incision is completed and the pleural cavity exposed, a suitable retractor should be inserted, the handle pointing towards the axilla, for ease of instrumentation and visibility. The superior, or inferior, costal cartilages of the opened interspace may be incised in order to achieve additional exposure. When sternal transection is required, the internal mammary vessels must be ligated.

Pericardiotomy

The phrenic nerve can be identified anterior to the hilar vessels by retracting the lung posteriorly (Figure 5). The pericardium can be inspected at this stage and, in the case of a significant tamponade, will be tense, with the absence of visible pulsations. To release a pericardial tamponade, an opening should be made parallel to, and at least 1-cm anterior to, the phrenic nerve, started with a blade, or sharp point of scissors. Blood clots can then be evacuated and any cardiac bleeding points identified and controlled, initially by digital pressure. It is not essential to close the pericardium after this procedure. In patients who do not have tamponade, but have arrested, internal cardiac massage is indicated.
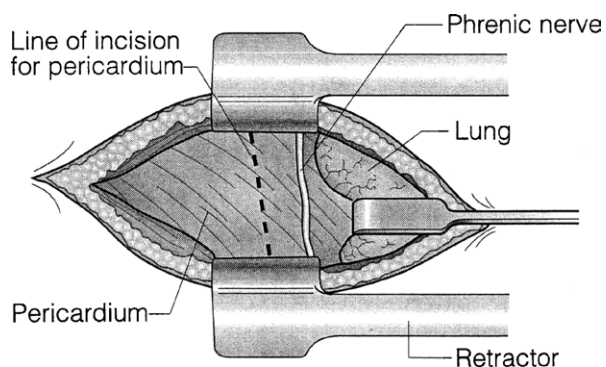

Figure 4 Left anterolateral thoracotomy. Copyright The Royal College of Surgeons of England. Reproduced with permission from Botha A et al. (2002) *Definitive Surgical Trauma Skills*.

Figure 5 Identification of the phrenic nerve. Copyright The Royal College of England. Reproduced with permission from Botha A et al. (2002) *Definitive Surgical Trauma Skills*.

Haemorrhage control

Partially occluding vascular clamps should be used to control major vessel and atrial bleeds. In the case of significant lung laceration, or widespread parencyhmal destruction, the hilum of the affected lung should be occluded with a vascular clamp, such as a Satinsky clamp, until a definitive surgical procedure can be performed. Air embolism can also be managed initially in this way and air evacuated from the left ventricle by needle aspiration.[14] With a beating heart, any attempt at repair should be delayed until initial resuscitative measures are completed. In the case of a non-beating heart, suturing may be performed before resuscitation and defibrillation.[9,14] In cardiac injuries, the whole heart should be examined to localise all sources of bleeding.

For temporary control of cardiac wound haemorrhage a Foley catheter may be inserted directly into the cardiac wound, after which the balloon can be inflated to control bleeding. The catheter may also be utilised for fluid infusion.[63] The tube of the catheter must be clamped and great care must be taken not to exert too much traction as this may pull the balloon out of the cardiac wound and, in so doing, increase the size of the hole.

Temporary control of haemorrhage from cardiac wounds can be achieved either by suturing with 3/0 non-absorbable vertical, or horizontal, mattress sutures, or the use of a stapling device. Suture repair of ventricular lacerations requires considerable dexterity and control of bleeding while placing multiple sutures, which exposes the surgeon to the risk of a contaminated needle stick injury.[79] The use of a standard skin stapler was assessed clinically by Macho et al. and was shown to be an effective and rapid technique in simple, single or multiple, cardiac wounds whilst eliminating the risk of a needle stick injury. However, the authors recommended that stapling must be considered a temporary measure and that staples be removed after definitive cardiorraphy in the operating theatre.[55] Great care must be taken to avoid inadvertent occlusion of, or trauma to, coronary vessels and horizontal mattress sutures placed under a vessel should prevent this occurring. Closure of posterior cardiac wounds may necessitate elevation of the heart for exposure and this is best accomplished in an operating theatre, where optimal lighting and equipment are available.[9] Temporary inflow occlusion of the superior and inferior venae cavae may be necessary to facilitate repair. Low pressure venous and atrial lacerations can be repaired with simple continuous sutures.

Adjunctive manoeuvres

Internal cardiac massage

Internal cardiac massage has been shown to produce an improved cardiac index, compared to external cardiac massage.[28] The technique for this has been described as a hinged clapping motion of the hands with the wrists apposed, resulting in ventricular compression proceeding from the apex to the base of the heart.[9] A one-handed massage technique is also possible though this is known to pose a small risk of myocardial perforation.

Internal defibrillation may be required to restore cardiac output, despite adequate filling pressures, especially in the event of ventricular fibrillation, or tachycardia. The energy settings are reduced to 15—30 J.

Aortic cross-clamping

Cross-clamping of the descending aorta leads to a temporary increase in the proximal arterial pressure and hence preservation of perfusion of the brain and heart. It is also used in attempts to limit subdiaphragmatic haemorrhage in both blunt and penetrating trauma. The descending thoracic aorta is occluded inferior to the left pulmonary hilum, which is best exposed by elevation of the left lung anteriorly and superiorly. The aorta must be separated from the oesophagus anteriorly and the pre-vertebral fascia posteriorly by blunt dissection, before occluding using a large vascular clamp, such as a DeBakey's. Care must be taken when clamping the aorta, in order to avoid avulsion of vital branches. This risk is minimised by incompletely encircling the aorta.

Overzealous fluid volume loading during cross-clamping may lead to cardiac failure as a result of acute ventricular dilatation and caution must also be exercised when releasing the clamp, in order to avoid a precipitous drop in blood pressure as flow is resumed. It should be noted that aortic cross-clamping has been shown to be a significant predictor of poor outcome during emergency thoracotomy, most probably related to the degree of haemodynamic compromise that necessitated the procedure.[2]

Measures following successful thoracotomy

Once haemorrhage has been arrested and cardiac output is returning, the patient requires rapid transfer to the formal operating theatre. Definitive exploration, repair and appropriate closure of the

original access procedure are best performed by a specialist surgeon in a controlled environment with suitable resources. Hypotensive resuscitation (sustaining systolic blood pressure at around 90 mmHg) should be employed, aiming for critical organ perfusion, whilst minimizing additional haemorrhage. Once effective cardiac function returns, the priority of further treatment shifts from the repair of injury and prevention of haemorrhage to maximisation of cardiac output and delivery of oxygen to the tissues. The penalty of aortic cross-clamping increases markedly when occlusion time exceeds 30 min. Therefore, the aortic clamp must be removed once effective cardiac function and systemic arterial pressures have been achieved.[9] Aortic declamping is associated with a sudden reperfusion of distal ischaemic tissues and subsequent release of inflammatory mediators into the cardiopulmonary system; therefore, careful monitoring is required in the immediate post-thoracotomy period. The oxygen carrying capacity can be enhanced by optimisation of cardiac contractility, by adequate filling and the maintenance of haemoglobin levels (above 10 mg/dL). Inotropic agents may also be utilised in order to improve myocardial function.

Discontinuation of resuscitation

The discontinuation of all resuscitative efforts requires careful judgement, having regard to the method of injury, a knowledge of the physiological indicators, both in the prehospital environment and on arrival in the emergency department, and an understanding of the factors predictive of a poor outcome following emergency thoracotomy. Specific endpoints need to be set to prevent undue prolongation of futile resuscitation efforts.

Termination of emergency thoracotomy should certainly be considered on the discovery of irreparable heart, or lung, injuries, asystolic arrest and the presence of other lethal trauma, such as a massive

Table 8 Factors suggesting discontinuation of resuscitation during thoracotomy

Systolic blood pressure remains <70 mmHg after 15 min despite fluid volume resuscitation

Self-sustaining rhythm is not achieved within 15 min of start of thoracotomy

Need for aortic cross-clamping in an attempt to restore myocardial and cerebral perfusion

Absence of a pericardial effusion without cardiac activity on opening of the chest

Emergence of signs of secondary devastating injuries with an independently poor outcome

head injury. Table 8 outlines the factors predictive of a poor outcome, and which suggest discontinuation of resuscitation efforts involving thoracotomy.[14,65]

Risks to medical staff

Several studies indicate that patients who sustain penetrating cardiac trauma are also at an increased risk of having infectious viral diseases, such as hepatitis and HIV infection.[31,46,76] This figure can be as high as 20% among the subgroup of patients requiring emergency department thoracotomy. Whilst on the whole this reflects the experience of emergency departments in the USA, consideration must be given to avoiding potentially high-risk activities in departments anywhere in the world. Emergency thoracotomy involves the rapid use of multiple surgical instruments and exposure to patients' blood is certain. As a result, the possibility of sustaining a significant HIV-seropositive exposure during emergency thoracotomy must be a matter of concern. Fortunately, the overall number of cases of occupation-related HIV seroconversion, as a result of patient contact, remains very low. Nevertheless, the application of appropriate guidelines and a selective approach to the use of emergency thoracotomy will minimise the risk of exposure to blood-borne pathogens.

Other options for management

Pericardiocentesis and subxiphoid pericardiotomy

Any patient who is physiologically unstable enough to require an emergency thoracotomy is unlikely to be suitable for either pericardiocentesis, or a subxiphoid pericardiotomy. However, pericardiocentesis may still have a place in the management of some patients with thoracic trauma, who are stable enough to move to the operating theatre for an urgent thoracotomy. Such patients may gain some benefit from at least the partial relief of an acute pericardial tamponade. Pericardiocentesis, or subxiphoid pericardiotomy, may also prove to be useful in cases of delayed pericardial effusion following recent thoracic trauma. The incidence of this condition is not known, although at least one series has been published on the subject.[39] Its conclusion was that subxiphoid pericardiotomy was an adequate form of therapy following diagnosis by ultrasound investigation.

However, the use of pericardiocentesis in thoracic trauma is a controversial subject. One of the major limitations is that it is not possible to evacuate

clotted pericardial haemorrhage by pericardiocentesis. The literature includes many series of cases in which pericardiocentesis is discussed as both a diagnostic and a therapeutic procedure. In one such review of 33 patients seen with penetrating cardiac injuries over a 7-year period, McFarlane and Branday concluded that pericardiocentesis was not helpful in making the diagnosis and was only performed as a resuscitative measure in unstable patients prior to thoracotomy. They also concluded that a high index of suspicion in patients with penetrating thoracic trauma, leading to expeditious thoracotomy, would result in the greatest salvage rate.[60] In their review of recent advances in the diagnostic tools used in the management of chest injuries, Mattox and Wall concluded that abdominal (FAST) ultrasound, performed by surgeons in the emergency department, makes diagnostic pericardiocentesis and subxiphoid pericardiotomy obsolete.[59] Similarly, in their series of 64 patients with penetrating cardiac injuries, Tavares et al. noted that performance of a subxiphoid pericardiotomy wastes valuable resuscitative time and risks releasing a tamponade without allowing adequate control of the bleeding source.[79] Overall, pericardiocentesis and subxiphoid pericardiotomy were not shown to be appropriate in the management of cases of thoracic trauma, unless the patient was physiologically stable, in which case they might be appropriate as temporary measures to improve cardiac output before urgent (operating department) thoracotomy, or to drain a delayed, or septic, pericardial effusion presenting late following trauma. They may also be appropriate diagnostic procedures for cases of suspected cardiac injury, where symptoms and signs are questionable.

Digital thoracotomy

The pleural space may be entered by the examining doctor's finger in order to feel for for conditions that might require further diagnostic, or therapeutic, measures. Examples of these are show in Table 9.[84] This procedure should not delay resuscitative efforts in an obviously moribund, or physiologically unstable, patient and must be followed by the placement of an intercostal chest drain.

Thoracoscopy

Thoracoscopy has been utilised mainly for the assessment and examination of thoracic structures during elective procedures.[89] The procedure can also be applied to the removal of clotted haemothoraces, to visualise the diaphragm for traumatic ruptures, to examine the pericardium, for the removal of foreign bodies and for the control of chest wall, or intrathoracic, bleeding.[45,51,57] Its use in cases where emergency thoracotomy is required has not been investigated.

FAST examination

The Focused Assessment with Sonography for Trauma (FAST) examination of the pericardium and abdomen has been a significant advance in the care of the trauma patient.[73] In one study of 238 victims of penetrating torso injury, the routine use of FAST was noted to be beneficial, with the detection of pericardial, or peritoneal, fluid being the most clinically useful gain, facilitating expeditious surgical care.[16]

By avoiding ionizing radiation, this examination has also the advantage of being able to be repeated as many times as required during the continued assessment and management of a trauma victim, and reduces collateral exposure of the treating team to ionising radiation in the emergency setting.

Summary

The term emergency thoracotomy has been applied to thoracotomy carried out in different environments, leading to a wide variation in its use in much of the literature. The term emergency department thoracotomy is that most commonly used in cases where thoracotomy was carried out as a resuscitative measure. The nomenclature should be clarified so that emergency thoracotomy is the term for any thoracotomy carried out as part of the resuscitative process, whether carried out on-scene, in the emergency department, or in the operating theatre.

Emergency thoracotomy may well be under-utilised in the specific group of patients who are likely to benefit the most from the procedure. Experience has shown that there is approximately a 10% salvage

Table 9 Findings with digital thoracotomy examination

Positive finding	Differential diagnosis
Tense pericardium with reduced cardiac pulsation	Suggestive of a pericardial effusion/tamponade
Evidence of pleural symphysis	Likely secondary to previous trauma or disease
Palpable holes in pericardium or diaphragm	Traumatic injury to thoracic structures
Palpable abdominal organs	Evidence of diaphragmatic rupture

rate following emergency thoracotomy in a population of patients that would otherwise have a 100% mortality rate and, therefore, this procedure should be carried out immediately, when indicated. Patients who have an isolated penetrating cardiac injury have the best prognosis, while moribund patients who have suffered blunt trauma, especially associated with extrathoracic injuries (in particular, severe head or spinal injuries), will generally have a dismal prognosis.

The keys to successful resuscitation of the traumatized heart are a high index of clinical suspicion, early recognition and rapid intervention. Departmental training, with moulage practice during regular education sessions, will aid in the recognition of clinical signs and speed appropriate intervention in cases where emergency thoracotomy is indicated.

Finally, routine and robust audit, as well as efforts to collect data prospectively, will help to improve upon and clarify the information on this fortunately uncommonly needed procedure.

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