EMERGENCY THORACOTOMY – THE INDICATIONS, CONTRAINDICATIONS AND EVIDENCE

BS Morgan[1], JP Garner[2]

[1]Core Trainee in Emergency Medicine, Northern General Hospital, Herries Road, Sheffield. [2]Consultant Colorectal Surgeon, The Rotherham NHS Foundation Trust, Moorgate Road, Rotherham.

Abstract

Emergency thoracotomy is a dramatic and controversial intervention which may be life saving after major torso trauma. Success rates are variable and differ widely according to mechanism of injury. This article outlines the current indications and contraindications to emergency thoracotomy and examines the evidence to support it accumulated over 40 years.

Introduction

Emergency Thoracotomy in the management of torso trauma remains one of the most controversial techniques available to the trauma surgeon or emergency physician. It may be performed at the scene as a pre-hospital emergency thoracotomy (PHET), in the Emergency Department (EDT) or emergently in the Operating Room (ORT). The indications and application have varied over the years from widespread usage with little regard to indication [1] to a virtually nihilistic denial of its utility [2]. This article discusses the indications, contraindications, basic techniques and outcome for emergency thoracotomy and examines the evidence for its use particularly in the pre-hospital and Emergency Department settings. More than 80% of thoracic injuries do not require surgery, emergently or otherwise, and can be managed with tube thoracostomy, supplemental oxygen, analgesia and physiotherapy [3]. An emergent thoracotomy should not be performed unless the team is capable of providing definitive surgical treatment and operative repair at the same time. The details of those skills are beyond the scope of this article but will be highlighted in future articles on penetrating cardiac injury and non-cardiac thoracic trauma.

Background

Trauma remains a leading cause of death world wide accounting for 56 per 100,000 deaths, and is the commonest cause of death of those under 35 years old [4]. Thoracic injury accounts for between a quarter and a half of all injuries [5] resulting in approximately 150, 000 deaths annually in the USA [4] and contributing to approximately half of all traumatic deaths [6]. Most thoracic trauma deaths occur within the first three hours from great vessel or cardiac disruption. In the UK, one third of all patients attended to by the London Helicopter Emergency Medical Services (HEMS) have suffered thoracic injury requiring specialist intervention [7]. Blunt thoracic trauma – mainly from Road Traffic Collisions – predominates in Europe with interpersonal violence accounting for only 5% of cases [8].

The treatment of chest injuries is many thousands of years old but has traditionally fared badly, with severe thoracic injury being widely regarded as fatal [9]. Thoracotomy for open cardiac massage as part of a medical cardiac arrest resuscitation was popularised by Schiff from 1874 onwards. The damning words of Theodor Billroth in 1883 that *"The surgeon who should attempt to suture a wound of the heart would lose the respect of his colleagues"* meant a further 14 years passed before Ludwig Rehn successfully repaired a right ventricular stab wound. A further 6 years passed before Hill performed his successful kitchen table top emergency thoracotomy and cardiorraphy in Montgomery Alabama in 1902. The advent of closed cardiac massage [10] in 1960 meant that thoracotomy no longer formed part of medical cardiac arrest resuscitation, but the Ben Taub Hospital group in Houston Texas suggested the techniques could be applied to cardiac arrest from penetrating chest trauma [11], and the foundations for EDT were laid.

Corresponding Author: Dr BS Morgan, Broad View, Grove Park, Pontnewydd, Torfaen NP44 1RN
Email: dr.beth.sian.morgan@googlemail.com

The Pathophysiology of Thoracic Trauma

Most simply this can be divided into blunt or penetrating mechanisms with the spectrum of blast injuries representing specific forms of each; it may also be considered on an anatomic basis as cardiac or non-cardiac thoracic injury. The relative frequency of each type of injury will vary by geographical location and is largely a function of the levels of interpersonal violence and the ease of availability of firearms.

In blunt trauma the mechanisms are usually deceleration or direct crush. In rapid deceleration the thoracic contents move at different rates according to their degree of fixation and this leads to shearing and tearing at points of relative fixity. The descending thoracic aorta, great vessels and bronchial tree are particularly prone to this type of injury known as the "Bell clanger effect". Compression injury may crush the heart between the sternum and thoracic vertebrae leading to contusion or even myocardial rupture. The lung parenchyma, although relatively elastic, may also be directly crushed and abdomino-thoracic crush may acutely raise the pressure within one or other cavity generating a ruptured diaphragm. Primary blast injury produces a picture of thoracic injury comparable to that of blunt compression [12].

Penetrating chest trauma generally produces a more discrete injury than blunt trauma and may involve the thoracic structures, singly or in combination. These include the heart, great vessels, lung and diaphragm. Less commonly injured are the airway, oesophagus, thoracic duct and spinal cord. These injuries can result in pneumo or haemo-thoraces, cardiac tamponade or bronchopleural fistulae. Secondary blast injury may produce penetrating chest injury from energised fragments.

Thoracic injuries can also be divided into those that are immediately life-threatening and those that are potentially life threatening (Table 1). Potentially life-threatening are so described

as they may initially be concealed but may later present as a fatal complication. If there is a delay in presentation then 'potentially life-threatening' injuries may become immediately life threatening at presentation and must be considered as such.

Immediately life threatening	Potentially life threatening
Airway obstruction	Cardiac contusion
Tension pneumothorax	Aortic disruption
Open pneumothorax	Simple pneumothorax
Massive haemothorax	Haemothorax
Flail Chest	Tracheobronchial disruption
Cardiac Tamponade	Diaphragmatic rupture
	Oesophageal perforation

Table 1. The immediate and potential life-threatening thoracic injuries [13].

Since the exact nature of intrathoracic injury may not be discernable at presentation, the indications for ET are defined by the physiological status at the scene and in the Emergency Department (ED), the *likelihood* of life-threatening intra-thoracic injury and mechanism of injury.

Indications and contraindications for Emergency Thoracotomy

The proliferation of studies reporting institutional results of EDT have allowed continued refinement of the indications for, and perhaps more importantly the contraindications to, the procedure aimed at maximising its success rate [14]

It is somewhat difficult to reach firm conclusions when reviewing the literature since outcomes have not been uniformly reported. This is compounded by the differing definitions used and reports combining both blunt and penetrating injury. In aggregate several broad concepts are generally accepted. While the definition of vital signs is well understood, signs of life (SOL) are defined as the presence of cardiac electrical activity, responsive pupils or spontaneous respiratory effort.

Indications

- Hypotension (systolic <70mmHg) persistently unresponsive to aggressive fluid resuscitation from significant intra-thoracic haemorrhage (>1500ml in chest drain), cardiac tamponade, systemic air embolus or tracheobronchial disruption.
- Witnessed cardiac arrest after isolated penetrating chest trauma with definite previous signs of life (<15 minutes of prehospital CPR)[15].
- Cross clamping of the thoracic aorta to halt uncontrollable abdominal haemorrhage as a pre-laparotomy manoeuvre [16].

Contraindications

- No signs of life after blunt thoracic trauma (>5 minutes of CPR) [15].
- No signs of life on scene and on arrival in the Emergency Department after 15 minutes of cardiopulmonary resuscitation.
- Cardiac arrest in a non-shockable rhythm for over 5 minutes.
- Co-existent severe head injury or multisystem trauma.
- Inexperienced medical staff or insufficient equipment [17].

Emergency Thoracotomy Technique

The standard approach is a 5th interspace left antero-lateral thoracotomy. This versatile incision can be extended across the midline as a "clamshell" and affords excellent exposure of the left pleural space and mediastinal structures. The sternum can be divided with a Lebshke knife, bone cutter, saw or heavy scissors. This incision can also be extended for a laparotomy, if necessary. The only indication for a primary right sided approach is the presence of an isolated right sided thoracic injury, and the patient has not yet arrested as internal cardiac massage can only be performed via the left chest. Box 1 outlines the rudiments of the technique of emergency thoracotomy whilst Table 2 outlines some of the possible courses of action after the chest has been opened.

Anaesthesia	The patient should be intubated and ventilated although in the moribund patient the procedure should not be delayed for the onset of anaesthesia. Anaesthetic agents with least cardiovascular effects such as ketamine are the preferred for induction in the conscious patient with vecuronium as the muscle relaxant, due to it's minimal effect on K+ and acid-base status [18].
Position	Supine with a wedge under the ipsilateral side to obtain a 15° tilt and full abduction of the ipsilateral arm. This will facilitate extending the incision to the axilla and improving exposure. Sterile preparation and draping of the ipsilateral chest.
Incision	From the sternal border in the 5th intercostal to the mid-axillary line. This is generally follows the inframammary fold. After the skin and subcutaneous fat are incised, the intercostal muscles, and parietal pleura are divided using scissors or blunt dissection. Ventilation should be temporarily halted at this stage to allow the lung to deflate and minimise further injury.
Retraction	Insert a rib spreader with the handle away from the operator; additional exposure can be achieved by dividing the 6th rib posteriorly.
Extension	Greater access can be achieved by dividing the distal sternum, thus converting to a "clamshell" thoracotomy allowing access to both hemithoraces and the mediastinum.

Box 1. The technique of emergency thoracotomy.

The Evidence for Emergency Department Thoracotomy

A review of the literature on EDT is complicated by the variation in terminology, sample size and reliability. Some centres use a protocol driven approach to EDT while others rely on the judgement of the treating physicians and surgeons. Ethical considerations prevent a randomised control trial and there are none cited in the literature, hence the evidence on which EDT practice is based comes from cases series and individual case reports, virtually all of which are retrospective. One significant issue when interpreting these studies is variation in the definition of and widespread interchangeable use of the two phrases 'signs of life' and 'vital signs'; no vital signs in this context is usually taken to mean the absence of a blood pressure or pulse but the presence of cardiac electrical activity or pupillary reflexes. An standardised definition, not only for the severity of injury but the basic signs of life, would allow statistically significant interpretation of retrospective information [1,21].

Early Reports

Trunkey's group [22] reported 168 cases of EDT following trauma between 1972 and 1978 and clearly demonstrated both clinical and cost utility in the procedure – there was an overall survival rate of 19.6% which rose to 24% if patients with irreversible head injuries were excluded. When survival was correlated with features at presentation those with no vital signs had a much worse outcome than those who were agonal or in profound shock (6.6% v 20% v 34.1% survival); similarly stab wounds did better than gunshot wounds and cardiac injuries fared better than great vessel injuries. The authors detailed the neurological sequelae of EDT

Findings	Action
Cardiac Tamponade	This should be evident by the bulging, tense pericardial sac and the emergency treatment is pericardiotomy with evacuation of the clot followed by occlusion of the cardiac defect.
Pulmonary/ Hilar Injuries	ED management is limited to control of massive haemorrhage or systemic air embolus. The hilum can be controlled by nylon tape occlusion, application of a Satinsky clamp or by lung rotation. Systemic air embolism may also be limited by selective ventilation of the unaffected lung, decreased ventilation pressure and volume and Trendelenburg position.
Great Vessel Injuries	These should be temporarily occluded by finger pressure; if accessible, small injuries can be repaired with 3-0 non-absorbable suture, but larger injuries, particularly of the arch vessels almost always necessitate extension of the anterolateral approach to either a midline or supraclavicular incision.
Aortic Cross-clamping	It is best achieved by elevating the left lung hilum and bluntly dissecting the descending aorta from the oesophagus and pre-vertebral fascia to allow application of a vascular clamp just above the diaphragm. It may be most useful in those patients with distal exsanguinating haemorrhage. The increase in afterload with an already compromised myocardium results in significant cardiac damage and eventual failure.
Internal cardiac massage	This maintains the viability of the arrested heart for longer than closed cardiopulmonary massage [19]; the heart is held between the two hands such that the fingers compress the ventricles – a one handed technique increases the rate of myocardial perforation. Internal defibrillation should be performed using internal paddles delivering 15-30 joules [20].

Table 2. Immediate operative management following emergency thoracotomy.

[23] in the long term survivors and all made good neurological recoveries that was apparent within 12 hours of recovery from surgery including those with no vital signs in the field. These outcomes were replicated by Ivatury et al [24] in patients with penetrating cardiac injuries. Of the 22 who were moving in the ambulance in transit but without vital signs or cardiac activity in the ER, EDT restored cardiac function in 16 (72.7%) with 8 making a complete neurological recovery (36.4%). Trunkey's series included 60 blunt trauma cases – two years later a consecutive series of 38 blunt trauma EDTs yielded no survivors regardless of age, sex or time from injury to arrival [25].

With the pace of evidence growing for EDT as a useful procedure, attention focussed on the role of EDT outside of the traditional University Hospital Level I trauma centre. An astonishing 47 thoracotomies as an emergency were performed in an urban community hospital in Detroit in a 1 year period [26] – 28% survived; they describe the presenting cardiac rhythm as a prognostic factor with just over half of the patients being in sinus rhythm or sinus tachycardia and all survivors were in this group – no patient presenting with bradycardia, asytole or ventricular fibrillation survived. Further excellent results from penetrating cardiac injury [27] reported a 57% (21/37) survival after EDT – most of the deaths were in those suffering cardiac gunshot wounds – a further 24/27 (89%) survived OR thoracotomy giving an overall survival after penetrating cardiac injury of 70%. Howard Champion reported 89 consecutive emergency bay thoracotomies, 85% of whom had no vital signs on arrival – 10 survived to discharge, all bar one being neurologically intact. Champion reports that a progressive increase in survival rate was identified with increasing use of the procedure over time [28].

American Perspective 1990-2000

A note of caution needs to be emphasized when reviewing the American trauma literature regarding EDT. Most of the published reports are from large urban trauma centres with significant experience with both blunt and penetrating trauma. These urban centres usually have a sophisticated pre-hospital system and rapid transport to the trauma centre. Clearly, time from injury to definitive care is critical for survival.

The Harbour View Medical Centre experience [2] in Seattle appeared to be less enthusiastic reporting on 112 EDTs over 4 years with an overall survival rate of only 1.8%. They had predominantly blunt trauma (79%), but even with penetrating trauma salvaged only 1 out of 24 patients. They identified that no patient requiring CPR from scene through transport to the ER survived, but that the presence of spontaneous respiration and a blood pressure in the field was associated with an 11.8% survival. They were the first group to raise the spectre of viral disease transmission from such a maximally invasive procedure as well as the financial costs of performing EDT. In a subsequent series of emergency thoracotomies [29] performed in the OR, this group increased their survival rate to 9% (3 of 34) all of which were from the eight penetrating injuries, again confirming the futility of resuscitative thoracotomy after blunt trauma irrespective of location of surgery.

Figures from New York [30] were markedly better with overall survival of 9.8% out of 163 EDTs – blunt trauma thoracotomy again yielded no survivors and the differential survival rates were 12 of 49 stab wounds (24.5%) and 4 of 85 gunshot wounds (4.7%). Further analysis concluded that EDT was most efficacious when 'directed' towards the treatment of penetrating thoracic injury and cardiac tamponade in particular. Out of 84 penetrating thoracic wounds, 56 had tamponade and the salvage rate was (21.4%) which was statistically significantly higher than survival when thoracotomy was for extrathoracic penetrating injury.

The benefits of OR thoracotomy over EDT were again [31] confirmed for penetrating cardiac injury when Blake *et al* reported a 100% survival for OR procedures compared to 22% for those performed in the ER. The authors suggest the differences may be due to differences in severity of injury or the inability to control cardiac bleeding during an EDT. Another factor may be that moribund patients required immediate thoracotomy, while in unstable patients there may be time to move to the operating room.

A large series of 463 thoracotomies (424 of which were EDT) from San Francisco [32] salvaged 61 patients (13%) – with success rates increasing in line with mechanism of trauma with survival being 2% after blunt injury, 8% after penetrating gunshot wounds and 34% for stab wounds. Survival was best in those patients who had suffered penetrating injury with moderate (BP 60-90mmHg) or profound shock (BP<60mmHg) prior to cardiac arrest with salvage of 56% and 64% respectively. No patient without signs of life – defined as full cardiopulmonary arrest and absent reflexes - in the field survived. Pre-hospital CPR does not preclude successful EDT although shorter duration improves the chances of success; the mean duration of CPR was 5.1 minutes for survivors compared with 9.1 minutes for non-survivors and in the salvaged group endotracheal intubation allowed toleration of a

mean of 9.4 minutes compared to 4.2 minutes in the non-intubated patients [33].

The first meta analysis of outcome after EDT was published 1992 combining 2294 patients from 23 studies [34]. Overall survival was 11% with penetrating trauma patients faring better than blunt (14% v 2%, p<0.01). Absence of signs of life at the scene was universally fatal as was blunt trauma with no signs of life on arrival in the ER.

Millham and Grindlinger [35] examined the 21 of 290 EDT patients who survived to the ICU following penetrating chest injury; eight died, and 13 survived but only nine were neurologically intact, thus restoration of cardiac output does not necessarily determine a successful outcome. All survivors had vital signs in the field or on arrival in the ER and seven of nine neurologically intact survivors were awake on ER arrival. The other two were moving extremities and the authors suggest mental state on arrival in ER may predict eventual neurological outcome. Ten neurologically intact survivors were reported out of a series of 273 EDTs; most (252) were performed for penetrating injury and included all ten survivors - all had vital signs at some stage, whereas only 49/242 non-survivors had vital signs [36].

Brown *et al* from Indianapolis [37] performed 160 EDTs over 7 years, all eleven blunt trauma victims died and were not further analysed. Despite a relatively poor overall survival rate of 2.7% (4 out of 149), they classified patients into 4 categories similar but in reverse to those of Ivatury *et al* [38]. Class I had no signs of life, Class II were agonal in EMD / PEA with no palpable output or blood pressure, Class III were in profound shock (BP<60mmHg) and Class IV had mild shock (BP 60-90mmHg). Nearly all patients (89%) were Class I or II at scene and did not improve after resuscitation – all died. Of the four survivors, three were Class III at scene and one Class IV; on this basis they recommend limiting EDT to those with penetrating chest injury presenting in Class III or IV. Six years later the same group [39] published a further 4 years worth of data comprising 65 penetrating injury EDTs; the proportion of Class I patients decreased considerably but the survival rate remained the same at 2.6%, again all from Class III and IV patients – they then concluded that abandoning EDT for Class I and II patients at scene and Class I on arrival at the ER would not miss potentially salvageable patients and would increase the yield of EDT to 16.2%.

Asensio *et al* [40] published one of the few prospective studies of EDT and analysed 105 penetrating cardiac wounds to identify whether a variety of trauma scores and physiological variables correlated with survival although not all thoracotomies were performed in the ED. They had an overall survival of 33% which decreased to 14% (10/71) in EDTs; analysis of prognostic factors is clouded by the fact that no differentiation is made between EDT and ORT. A single surgeons individual experience does not appear to be any better than those of a department, with 7 survivors out of 102 EDTs performed or directly supervised by a single surgeon over 13 years. All survivors were from penetrating injury and not in full cardiac arrest when found by the paramedics [41].

An excellent review and meta analysis was published in 2000 by the surgical staff of the Uniformed Services University of the Health Sciences in Maryland [42] and collected 4620 cases from 24 studies – the overall survival rate was 7.4 % (8.8% for penetrating trauma and 1.4% for blunt), the majority of whom were neurologically intact. Stab wounds fared better (16.8% survival) than gunshot wounds (4.3%) and thoracic wounds did better than abdominal penetrating trauma (10.7% v 4.5%) – penetrating cardiac wounds did best of all with an overall survival of 19.4%. When survival in relationship to the presence of signs of life was considered, survival fell from 11.5% for those who had signs of life (SOL) in the ED to 8.9% for those who lost SOL in transport down to only 1.2% in those who had absent SOL in the field. That overall survival rate was matched by a report from Michigan [43] which had a survival rate of 7.9% after EDT from 152 cases over 17 years, no gunshot wound survived EDT, and the authors demonstrated the enormous improvement in survival if the patient is fit enough to make to the OR as the survival rate for the 150 ORTs was 74%.

US Experience from 2001

The 1980's and 90's saw a large number of institutional retrospective analyses of data most of which edged towards formalising the indications, and more importantly the contraindications to EDT. This was reflected in the implementation of institutional protocols and later publications outlined the impact of these policies. The Boston Medical Centre protocol [44] allowed EDT for cardiac tamponade after penetrating injury in patients who had had signs of life at the scene or since. Introduction of the protocol reduced the mean number of EDTs from 32.2 to 8.1 cases per year with an increase of survival from 4% to 20%. The American College of Surgeons (ACS) produced Practice Management Guidelines [17] in 2001 based on systematic review of over 30 years of data. The ACS reviewed 7,035 EDTs from 42 studies; survival was 500/4,482 (11.2%) for penetrating injuries and 1.6% for blunt trauma. The highest survival rates were for isolated penetrating cardiac injury (31.1%). No comment was made with regards to quality of life or cost/benefit ratio.

In the same year Miglietta et al [1] surveyed over 1000 members of the Eastern and American Associations for the Surgery of Trauma about their indications and practice for EDT. It revealed a marked lack of agreement regarding the indications for EDT, especially in blunt trauma where practice was much more liberal than the guidelines would suggest. Conformity was also hampered by variance in the definitions of signs of life. A study [45] looking specifically at the location of thoracotomy found no difference in outcome for stab wounds but highlighted the benefits of OR thoracotomy for gunshot wounds of the chest with a 22 times increase in survival. There was a 13 fold improvement if the emergency thoracotomy was performed in a specialised resuscitation room within the ED as opposed to an 'ordinary' EDT. This reflects some of the differences between US and UK practice as many American EDs have a dedicated room equipped to the level of an operating room immediately adjacent to it. A cost-utility analysis of the procedure for both blunt and penetrating injury a found that it was only cost effective for penetrating trauma and that the potential costs of occupational transmissible disease exposure to health care workers did not affect it [46].

The EDT experience from Philadelphia has recently been published in a series of papers examining different aspects of the procedure and its outcomes but all utilising the same series of patient data analysed retrospectively, albeit in slightly different time periods since 2000. One hundred and eighty EDTs for penetrating injury were divided according to whether they arrived in the ED by EMS transport or private/police vehicle [47]. In the 88 patients in the EMS transported group, nearly 90% had a field intervention and seven (8%) survived to hospital discharge compared to no field interventions in the 92 transported by private or police vehicle in whom 16 (17.4%) survived to discharge. The authors strongly support adherence to a policy of 'scoop and run'. A specific subgroup – those who underwent EDT to limit intra-abdominal exsanguination– were also analysed [48]. Fifty patients were treated for this indication, all bar one due to gunshot wounds. Perhaps unusually, over three quarters of this group had ER signs of life prior to EDT. Eight (16%) survived to leave hospital neurologically intact after prolonged stays in the Intensive Care Unit (mean stay 36.3 days) and massive blood transfusion (mean transfusion = 28.6 units ± 17.3 units) suggesting that despite the high costs, pre-laparotomy EDT for

exsanguinating abdominal haemorrhage is still worth while. In contrast to the growing trend for conservatism in EDT, these authors have published an article entitled 'Emergency Department Thoracotomy: survival of the least expected' [49] in which they report several neurologically intact survivors after suffering *'multiple gunshot wounds, abdominal exsanguinations, asystole or agonal initial cardiac rhythms, unobtainable vital signs and undetectable signs of life'*, thus application of a strict policy for EDT selection would have denied these patients the chance of survival. Their recommendation is for EDT after penetrating injury if signs of life were evident in the field and there has been rapid pre-hospital transportation. Somewhat perversely the same group have also published a further subset analysis of their data looking specifically at cardiac injuries prompting EDT and suggest that survival is not as good as previously suggested. Survival was 8 out of 94 penetrating cardiac injuries requiring EDT (8%), predominantly from the small number of stabbings (4 of 12 (33%) survivors) compared to 4 out of 82 gunshot wounds (5%). They suggest that in the prevailing urban climate of trauma in the USA where gunshot wounding predominates, a penetrating cardiac injury *per se* can no longer be viewed as a good prognostic feature in EDT [50].

The Denver Experience

Since 1979 the department of surgery at Denver General Hospital has maintained a prospective database of all EDTs performed there, building on an earlier retrospective analysis of 146 patients undergoing the procedure since 1974 which provided the unit with guidelines which they have subsequently followed in a prospective manner [51]. It is the largest single database of EDT data in the world and has contributed approximately one fifth of all data for published meta analyses. The first 400 patients (including the earlier 146) were reported in 1982 [52]. Half were performed for blunt trauma, 37% for gunshot injury and 14% for stab wounds – 106 survived EDT to make transfer to the OR, 28 were admitted to ICU but only 16 were discharged from hospital, four with severe neurological impairment giving a neurologically intact survival rate of 3%. They identified four factors predictive of poor prognosis ie death or neurologically disabled survival: blunt trauma without signs of life in the ER; penetrating torso trauma without field signs of life; following thoracotomy without tamponade absence of cardiac activity and aortic clamping was universally fatal. Five years later [53] they reported a further 232 patients which largely confirmed their earlier findings, with a neurologically intact survival rate of 3.6%. This paper attempted to stratify survival against prognostic features evident on arrival in the ER rather than encompassing on scene information which could be unreliable. They used three groups, I - those who had no signs of life on arrival in the ER, II - those that had signs of life but no vital signs on arrival, and III- those that had vital signs on arrival to the ER. For group I survival was 11/481 (2%), but 5 of these survivors were neurologically damaged which included the 3 blunt trauma and one gunshot wound survivors. Group II fared better with 4/38 surviving (11%), all neurologically intact and Group III did best of all with 14 out of 113 patients surviving (12%) with only one neurologically impaired. Aside from further confirming the need for a selective application of EDT, this article also highlighted the need for consensus as to the definitions and interpretation of the phrases 'signs of life' and 'vital signs'. The Denver group have utilised strict definitions for both these terms such that no signs of life equates to clinical death without detectable blood pressure, respiratory or motor effort, cardiac electrical activity or papillary activity. No vital signs implies no palpable blood pressure but demonstrable electrical activity respiratory effort or papillary activity. In this study, Group II had no vital signs but identifiable pupillary reflexes.

In 1998 the number of patients had risen to 950, of which 868 had complete medical records for analysis (and coroner's reports confirmed no survivors amongst the remainder) [54]. The proportion of blunt trauma EDTs had fallen slightly from 51% to 45% and neurologically intact survival increased marginally to 3.9%. Survival was best for isolated stab wounds to the heart with tamponade (29% survival), whilst gunshot wounds did uniformly poorly (2/112 cardiac gunshot wounds survived). The authors present their decision making algorithm for EDT for both blunt and penetrating injury and continue to recommend liberal application of EDT after penetrating trauma cardiac arrest

Evidence from outside the USA

This is limited both in the number of reports and the numbers of patients therein; hence care must be exercised when interpreting their outcomes. The first series from outside of the USA reported 45 cases from Groot Schuur Hospital in South Africa; none of the 13 blunt trauma cases survived whereas one quarter of the 32 penetrating injuries survived – seven out of this eight had cardiac tamponade [55]. Considering the relative dearth of serious trauma overall in UK, and penetrating injury in particular, when compared to the USA, it is interesting to note that the only reports in the literature detailing experience and outcomes of pre-hospital thoracotomy are British and come from the London Helicopter Emergency Medical Service (HEMS) based at the Royal London Hospital. They have sequentially published their increasing, and for UK fairly unique, experience. They reported their early experience in 1994 when in a 12 month period they performed 16 emergency thoracotomies, nine of which were performed on scene – 11 were for blunt trauma and no patients survived. The authors recommended on-scene thoracotomy should be abandoned [56]. A further report detailed 16 EDTs performed [57] between 1991-1994 of which there was only a single survivor which occurred after a thoracic stab wound – it is likely that some of these patients have previously been reported in their earlier report. Pre-hospital thoracotomy was again highlighted in their 2000 paper [58]; 39 on scene thoracotomies were performed in six years with 4 surviving to hospital discharge, 3 of whom were neurologically intact, all survivors had cardiac tamponade. Again those with signs of life at the scene did better with the survivors equally divided between those who lost their pulse prior to arrival of the HEMS team (they received 4 and 5 minutes of basic bystander life support respectively) and those who lost output after the HEMS team arrived. The most recent analysis of HEMS data reported on 8 years of HEMS flights for 670 consecutive cases of major thoracic injury – emergency thoracotomy was performed in 53 with an overall 18% survival; this was 3/31 on scene and 7/22 in the EDT or OR but unfortunately the paper does not discriminate further between these two groups [7].

The Department of Surgery in Baragwanath Hospital South Africa [59] reported a massive series of 846 EDTs over a 12 year period with survival in 26/312 stab wounds (8.3%), 16/358 (4.4%) and 1/176 (0.6%) although no clear distinction is made between which surgeries were true EDTs and which were undertaken in the OR. A Turkish group reported a single survivor out of 6 EDTs for blunt thoracic trauma whereas they attained a 91% survival for emergent OR thoracotomy after blunt injury [60]. Interestingly the epidemic of penetrating trauma that besets the USA does not appear to have befallen Canada with a University surgical department reporting only 27 major cardiac injuries over nine years, 16 of which were penetrating injury – only one of 16 EDTs survived [61].

The European experience with EDT continues to be somewhat sparse and rather dismal; a busy Norwegian trauma centre reported only 10 EDTs in 5 years, seven of which were for blunt trauma and there were no survivors despite 6 of them having signs of life either at scene, in transit or in the ER [62]. An interesting study from Austria [63] has reported the outcome of emergency thoracotomy

after blunt trauma cardiac arrest solely to institute open chest cardiopulmonary resuscitation rather than relief of tamponade or cessation of haemorrhage. Four out of 38 people survived, 2/28 of whom had EDT. Outcomes were equally poor in the West Indies where only 1 patient survived to hospital discharge after EDT out of 13 procedures performed over 11 years [64].

Bleetman *et al* [65] reported 25 emergency thoracotomies from the Glasgow Royal Infirmary, 17 of which were performed in the ED and in a reflection of UK trauma 23 had been stabbed; there was a single gunshot and one blunt trauma. One of 17 (5.6%) of the EDTs survived and 13 had no vital signs on arrival. Sixteen years of admissions to a UK regional cardiothoracic unit yielded 76 stab wounds to the chest, only 4 required EDT, three of whom survived [66]. The most recent UK experience of penetrating chest trauma is reported from Edinburgh where a three year period saw 120 patients treated for penetrating thoracic injury – there were only 2 gunshot wounds and only 6 patients underwent EDT! [67].

'Scoop and Run' versus 'Stay and Play'

This long running debate for trauma management in general has also been examined in the context of major thoracic injury. Ivatury's group [38] attempted to classify EDT patients according to the quality of the signs of life on arrival in the ER; Groups I (Profound shock) and II (agonal) had identical 29% survival rates compared to 14% survival for those dead on arrival (Group III) - none of those in Group IV (dead on scene) survived. Irrespective of group, survival was better for cardiac than non-cardiac wounds and for stab wounds than gunshot wounds. Overall survival was 7/44 (16%). If outcome after EDT is compared between those who underwent in-field stabilisation and those who were transported immediately to the ER, no patients clinical status improved from scene to ER after field resuscitation, a greater number of patients arrived with vital signs after immediate transportation and survival was also significantly better in the immediate transport group (p=0.02). There was no difference in injury severity between the groups [68]. This was confirmed, albeit with smaller numbers in a trial from South Carolina which compared EDT outcomes before (62 patients) and after (10 patients) a policy of mandatory 'scoop and run' – the overall survival rates were 3.2% v 10% respectively [69].

Frezza and Mezghebe [70] analysed 7 years of emergency department thoracotomies in association with pre-hospital data taken from the Emergency Medical Service reports and identified a pre-hospital time of more than 30 minutes as being an important prognostic factor in surviving EDT. The Philadelphia experience [47] has already been detailed above and strongly supported 'Scoop and Run' as EDT was twice as successful in those transported to the ED in private/police vehicles without pre-hospital intervention as those transported by EMS.

Paediatric Thoracotomy

The first study to examine whether EDT for paediatric patients was in any way different from in adults was published in 1987 [71] – over a 5 year period 17 paediatric trauma victims underwent EDT – 15 for multisystem blunt injury and two for isolated penetrating trauma – there were no survivors. The Denver group published a subset analysis of their prospective database in 1989 having identified 83 EDTs performed on under 18's [72]. Fifty seven per cent were for blunt trauma, 30% for gunshot wounds and 13% for stab wounds – survival rates were 9% (1/11) for stab wounds, 4% (1/25) for gunshot wounds an 2%(1/47) for blunt injury; of those who arrived in the ED without vital signs only one out of 69 survived compared with 2/14 that arrived with vital signs. They concluded that indications for EDT in children should be the same as in adults. A further small series from California of 23 (15 blunt, 8 penetrating) children salvaged only a single patient – this was after penetrating injury – all had undergone optimal field care, including intubation in three quarters of cases [73].

Summary

Emergency thoracotomy in the resuscitation of major torso trauma remains a much debated technique some 40 years after it was introduced in to mainstream practice. That it can be a life saving procedure in selected circumstances is beyond doubt, the issue remains as to identifying what those circumstances are so as to maximise neurologically successful outcomes and limit the costs and potential occupational disease exposure in futile interventions.

The liberal application of thoracotomy in the resuscitation of blunt trauma cannot be justified and should only be undertaken when there are documented signs of life in the emergency department or within five minutes prior to arrival; prolonged (>5mins) CPR after blunt injury equates to fatality.

When considering penetrating trauma, EDT is an acceptable intervention when vital signs have been present at some stage (on scene, in transit or in the ED) and pre-hospital transport times have been less than 30 minutes or less than 15 minutes of CPR have taken place.

All precautions should be taken to prevent inadvertent injury or occupational exposure to blood borne disease to those undertaking the procedure; outcomes are enormously better if the thoracotomy can be delayed until arrival in an operating room.

Acknowledgement

The authors would like to thank Dr Jim O'Connor, Associate Professor Surgery, University of Maryland School of Medicine & Director Thoracic And Vascular Trauma, R Adams Cowley Shock Trauma Center, Baltimore, Maryland USA for his helpful comments regarding the manuscript.

References

1. Miglietta MA, Robb TV, Eachempati SR *et al.* Current opinion regarding indications for emergency department thoracotomy *J Trauma* 1993; **34(3)**: 332-6.
2. Esposito TJ, Jurkovich GJ, Rice CL, Maier RV, Copass MK, Ashbaugh DG. Reappraisal of emergency room thoracotomy in a changing environment. *J Trauma* 1991; **31(7)**: 881-5
3. von Oppell UO, Bautz P, De Groot M. Penetrating thoracic injuries: what we have learnt. *Thorac Cardiovasc Surg* 2000; **48(1)**: 55-61.
4. Jerome LS, Siram S, Williams D, Mezghebe H. Epidemiology of trauma deaths in a Level-1 Trauma Centre Predominantly among African Americans–Implications for Prevention. *Ann Thorac Surg* 1989; **47(2)**: 250-3.
5. LoCicero J, Mattox KL. Epidemiology of chest trauma. *Emerg Med Serv* 2004; **33(8)**: 44-7
6. Odell JA. Thoracotomy. In Westaby S, Odell JA, eds. Cardiothoracic trauma. London. Arnold, 1999 pp138-146
7. Athanasiou T, Krasopoulos G, Nambir P *et al.* Emergency thoracotomy in the prehospital setting: a procedure requiring clarification. *Eur J Cardiothorac Surg* 2004; **26**: 377-385
8. Westaby S. The pathophysiology of chest traum. In Westaby S, Odell JA, eds. Cardiothoracic trauma. London. Arnold, 1999 pp138-146
9. Hunt PA, Greaves I, Owens WA. Emergency Thoracotomy in Thoracic Trauma - a review. *Injury* 2006; **37**: 1-19
10. Acosta P, Varon J, Sternback G, Baskett P. Kouwenhoven, Jude and Knickerbocker. The introduction of defibrillation and external chest compressions into modern resuscitation. *Resuscitation* 2005; **64(2)**: 139-143
11. Beall AC Jr, Diethrich EB, Crawford HW, Cooley DA, De Bakey ME. Surgical management of penetrating cardiac injuries. *Am J Surg* 1966; **112(5)**: 686-92
12. Garner JP. Blast Injury. In Greaves I, Porter K, Garner JP, eds. Trauma Care Manual 2nd Ed. London. Arnold 2009; pp215-222
13. Tai NRM, Boffard KD. Thoracic trauma: principles of management. *Trauma* 2003; **5**: 123-136
14. Doll D, Bonnano F, Smith MD, Degiannis E. Emergency Department Thoracotomy (EDT). *Trauma* 2005; **7**: 105-8
15. Powell DW, Moore EE, Cothren CC *et al.* Is emergency department resuscitative thoracotomy futile care for the critically injured patient requiring prehospital cardiopulmonary resuscitation? *J Am Coll Surg* 2004; **199(2)**: 211-5
16. Cothren CC, Moore EE. Emergency department thoracotomy for the critically injured patient: Objectives, indications, and outcomes. *World J*

Emerg Surg 2006; **1**: 4 doi:10.1186/1749-7922-1-4
17. American College of Surgeons – Committee on Trauma. Practice management guidelines for emergency department thoracotomy. *J Am Coll Surg* 2001; **193**: 303-9
18. Chandola HC. Emergency Anaesthetic Management of Extensive Thoracic Trauma. *Ind J Anaesth* 2007; **51(5)**: 392- 400
19. Mackay JH, Powell SJ, Osgathorp J, Rozario CJ. Six-year prospective audit of chest reopening after cardiac arrest. *Surg Gynecol Obstet* 1992; **175(2)**: 97-101.
20. Hunt PA. Thoracic Injury. In Greaves I, Porter K, Garner JP eds. Trauma Care Manual 2nd Ed. London. Arnold 2009; p78
21. Coimbra R, Pinto MC, Razuk A, Aguiar JR, Rasslan S. Penetrating cardiac wounds: predictive value of trauma indices and the necessity of terminology standardization. *Am Surg* 1995; **61(5)**: 448-52.
22. Baker CC, Thomas AN, Trunkey DD. The role of emergency room thoracotomy in trauma. *J Trauma* 1980; **20(10)**: 848-55.
23. Baker CC, Caronna JJ, Trunkey DD. Neurologic outcome after emergency room thoracotomy for trauma. *Am J Surg* 1980; **139(5)**: 677-81.
24. Ivatury RR, Shah PM, Ito K, Ramirez-Schon G, Suarez F, Rohman M. Emergency room thoracotomy for the resuscitation of patients with "fatal" penetrating injuries of the heart. *Ann Thorac Surg* 1981; **32(4)**: 377-85
25. Bodai BI, Smith JP, Ward RE, O'Neill MB, Auborg R. Emergency thoracotomy in the management of trauma. *J Trauma* 1982; **22(6)**: 487-91
26. Brautigan MW, Tietz G. Emergency thoracotomy in an urban community hospital: initial cardiac rhythm as a new predictor of survival. *Am J Emerg Med* 1985; **3(4)**: 311-5.
27. Tavares S, Hankins JR, Moulton AL *et al.* Management of penetrating cardiac injuries: the role of emergency room thoracotomy. *Ann Thorac Surg* 1984; **38(3)**: 183-7
28. Danne PD, Finelli F, Champion HR. Emergency bay thoracotomy. *J Trauma* 1984; **24(9)**: 796-802.
29. Jurkovich GJ, Esposito TJ, Maier RV. Resuscitative thoracotomy performed in the operating room. *Gen Thorac Cardiovasc Surg* 2008; **56(5)**: 222-5.
30. Ivatury RR, Kazigo J, Rohman M, Gaudino J, Simon R, Stahl WM. "Directed" emergency room thoracotomy: a prognostic prerequisite for survival. *J Trauma* 1987; **27(9)**: 1066-73.
31. Blake DP, Gisbert VL, Ney AL *et al.* Survival after emergency department versus operating room thoracotomy for penetrating cardiac injuries. *Am Surg* 1992; **58(6)**: 329-32
32. Lorenz HP, Steinmetz B, Lieberman J, Schecoter WP, Macho JR. Emergency thoracotomy: survival correlates with physiologic status. *Curr Surg* 1988; **45(2)**: 107-10.
33. Durham LA 3rd, Richardson RJ, Wall MJ Jr, Pepe PE, Mattox KL. Emergency center thoracotomy: impact of prehospital resuscitation. *J Trauma* 1992; **32(6)**: 775-9.
34. Boyd M, Vanek VW, Bourguet CC. Emergency room resuscitative thoracotomy: when is it indicated? *J Trauma* 1992; **33(5)**: 714-21.
35. Millham FH, Grindlinger GA. Survival determinants in patients undergoing emergency room thoracotomy for penetrating chest injury. *J Trauma* 1993; **34(3)**: 332-6
36. Mazzorana V, Smith RS, Morabito DJ, Brar HS. Limited utility of emergency department thoracotomy. *Am Surg* 1994; **60(7)**: 516-20
37. Brown SE, Gomez GA, Jacobson LE, Scherer T 3rd, McMillan RA. Penetrating chest trauma: should indications for emergency room thoracotomy be limited? *Am Surg* 1996; **62(7)**: 530-3.
38. Roberge RJ, Ivatury RR, Stahl W, Rohman M. Emergency Department thoracotomy for penetrating injuries: predictive value of patient classification. *Am J Emerg Med* 1986; **4(2)**: 129-35
39. Ladd AP, Gomez GA, Jacobson LE, Broadie TA, Scherer LR 3rd, Solotkin KC. Emergency room thoracotomy: updated guidelines for a level I trauma center. *Am Surg* 2002; **68(5)**: 421-4.
40. Asensio JA, Berne JD, Demetriades D *et al.* One hundred five penetrating cardiac injuries: a 2-year prospective evaluation. *J Trauma.* 1998; **44(6)**: 1073-82.
41. Kennedy F, Sharif S. Emergency room thoracotomy: a single surgeon's thirteen-year experience. *Am Surg* 2000; **66(1)**: 56-60
42. Rhee PM, Acosta J, Bridgeman A, Wang D, Jordan M, Rich N. Survival after emergency department thoracotomy: review of published data from the past 25 years. *J Am Coll Surg* 2000; **190(3)**: 288-98
43. Tyburski JG, Astra L, Wilson RF, Dente C, Steffes C. Factors affecting prognosis with penetrating wounds of the heart. *J Trauma* 2000; **48(4)**: 587-90
44. Aihara R, Millham FH, Blansfield J, Hirsch EF. Emergency room thoracotomy for penetrating chest injury: effect of an institutional protocol. *J Trauma.* 2001; **50(6)**: 1027-30
45. Karmy-Jones R, Nathens A, Jurkovich GJ *et al.* Urgent and emergent thoracotomy for penetrating chest trauma. *J Trauma* 2004; **56(3)**: 664-8
46. Brown TB, Romanello M, Kilgore M. Cost-utility analysis of emergency department thoracotomy for trauma victims. *J Trauma* 2007; **62(5)**: 1180-5
47. Seamon MJ, Fisher CA, Gaughan J et al. Pre-hospital procedures before emergency department thoracotomy: "scoop and run" saves lives. *J Trauma* 2007; **63(1)**: 113-20
48. Seamon MJ, Pathak AS, Bradley KM *et al.* Emergency department thoracotomy: still useful after abdominal exsanguination? J Trauma 2008; **64(1)**: 1-7
49. Seamon MJ, Fisher CA, Gaughan JP, Kulp H, Dempsey DT, Goldberg AJ. Emergency department thoracotomy: survival of the least expected. *World J Surg* 2008; **32(4)**: 604-12.
50. Molina EJ, Gaughan JP, Kulp H, McClurken JB, Goldberg AJ, Seamon MJ. Outcomes after emergency department thoracotomy for penetrating cardiac injuries: a new perspective. *Interactive Cardiovasc Thorac Surg* 2008; **7(5)**: 845-8
51. Moore EE, Moore JB, Galloway AC, Eiseman B. Postinjury thoracotomy in the emergency department: A critical evaluation. *Surgery* 1979; **86**: 590-8
52. Cogbill TH, Moore EE, Millikan JS, Cleveland HC. Rationale for selective application of emergency department thoracotomy in trauma. *J Trauma* 1983; **23**: 453-60
53. Baxter BT, Moore EE, Moore JB, Cleveland HC, McCroskey BL, Moore FA. Emergency department thoracotomy following injury: critical determinants for patient salvage. *World J Surg* 1988; **12(5)**: 671-5.
54. Branney SW, Moore EE, Feldhaus KM, Wolfe RE. Critical analysis of two decades of experience with postinjury emergency department thoracotomy in a regional trauma center. *J Trauma* 1998; **45(1)**: 87-94
55. Lewis G, Knottenbelt JD. Should emergency room thoracotomy be reserved for cases of cardiac tamponade? Injury 1991; 22(1): 5-6
56. Purkiss SF, Williams M, Cross FW, Graham TR, Wood A. Efficacy of urgent thoracotomy for trauma in patients attended by a helicopter emergency medical service. *J R Coll Surg Edinb* 1994; **39(5)**: 289-91
57. Jahangiri M, Hyde J, Griffin S et al. Emergency thoracotomy for thoracic trauma in the accident and emergency department: indications and outcome. *Ann R Coll Surg Engl* 1996; **78(3)**: 221-4
58. Coats TJ, Keogh S, Clark H, Neal M. Prehospital resuscitative thoracotomy for cardiac arrest after penetrating trauma: rationale and case series. *J Trauma* 2001; **50(4)**: 670-3
59. Velmahos GC, Degiannis E, Souter I, Allwood AC, Saadia R. Outcome of a strict policy on emergency department thoracotomies. Arch Surg 1995; 130(7):774-7.
60. Balkan ME, Oktar GL, Kayi-Cangir A, Ergül EG. Emergency thoracotomy for blunt thoracic trauma. *Ann Thorac Cardiovasc Surg* 2002; **8(2)**: 78-82
61. Alanezi K, Milencoff GS, Baillie FG, Lamy A, Urschel JD. Outcome of major cardiac injuries at a Canadian trauma center. *BMC Surg* 2002; 10; **2**: 4
62. Søreide K, Søiland H, Lossius HM, Vetrhus M, Søreide JA, Søreide E. Resuscitative emergency thoracotomy in a Scandinavian trauma hospital - is it justified? *Injury* 2007; **38(1)**: 34-42
63. Fialka C, Sebök C, Kemetzhofer P, Kwasny O, Sterz F, Vécsei V. Open-chest cardiopulmonary resuscitation after cardiac arrest in cases of blunt chest or abdominal trauma: a consecutive series of 38 cases. *J Trauma* 2004; **57(4)**: 809-14
64. Cawich SO, Mitchell DI, Williams EW *et al.* Emergency department thoracotomy in Jamaica: a case controlled study. *Int J Surg* 2007; **5(5)**: 311-5
65. Bleetman A, Kasem H, Crawford R. Review of emergency thoracotomy for chest injuries in patients attending a UK Accident and Emergency department. *Injury* 1996; **27(2)**: 129-32.
66. Ashraf SS, Volans AP, Sharif H *et al.* The management of stab wounds to the chest: sixteen years' experience. *J R Coll Surg Edinb* 1996; **41(6)**: 379-81.
67. Ferris JD, Smith I, Robertson CE. Emergency department at the cutting edge. *Eur J Emerg Med* 2008; **15(2)**: 67-70
68. Ivatury RR, Nallathambi MN, Roberge RJ, Rohman M, Stahl W. Penetrating thoracic injuries: in-field stabilization vs. prompt transport. *J Trauma* 1987; **27(9)**: 1066-73
69. Clevenger FW, Yarbrough DR, Reines HD. Resuscitative thoracotomy: the effect of field time on outcome. *J Trauma* 1988; **28(4)**: 441-5.
70. Frezza EE, Mezghebe H. Is 30 minutes the golden period to perform emergency room thoratomy (ERT) in penetrating chest injuries? *J Cardiovasc Surgery (Torino)* 1999; **40(1)**: 147-51.
71. Beaver BL, Colombani PM, Buck JR, Dudgeon DL, Bohrer SL, Haller JA Jr. Efficacy of emergency room thoracotomy in pediatric trauma. *J Pediatr Surg* 1987; **22(1)**: 19-23.
72. Rothenberg SS, Moore EE, Moore FA, Baxter BT, Moore JB, Cleveland HC. Emergency Department thoracotomy in children – a critical analysis. *J Trauma* 1989; **29(10)**: 1322-5
73. Sheikh AA, Culbertson CB. Emergency department thoracotomy in children: rationale for selective application. *J Trauma* 1993; **34(3)**: 323-8