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REVIEW ARTICLE

Should pre-hospital resuscitative thoracotomy be reserved only for penetrating chest trauma?

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Abstract

Purpose The indications for pre-hospital resuscitative thoracotomy (PHRT) remain undefined. The aim of this paper is to explore the variation in practice for PHRT in the UK, and review the published literature.

Methods MEDLINE and PUBMED search engines were used to identify all relevant articles and 22 UK Air Ambulance Services were sent an electronic questionnaire to assess their PHRT practice.

Results Four European publications report PHRT survival rates of 9.7, 18.3, 10.3 and 3.0% in 31, 71, 39 and 33 patients, respectively. All patients sustained penetrating chest injury. Six case reports also detail survivors of PHRT, again all had sustained penetrating thoracic injury. One Japanese paper presents 34 cases of PHRT following blunt trauma, of which 26.4% survived to the intensive therapy unit but none survived to discharge. A UK population reports a single survivor of PHRT following blunt trauma but the case details remain unpublished. Ten (45%) air ambulance services responded, each service reported different indications for PHRT. All perform PHRT for penetrating chest trauma, however, length of allowed pre-procedure down time varied, ranging from 10 to 20 min. Seventy percent perform PHRT for blunt traumatic cardiac arrest, a procedure which is likely to require aggressive concurrent circulatory support, despite this only 5/10 services carry pre-hospital blood products.

Conclusions Current indications for PHRT vary amongst different geographical locations, across the UK, and worldwide. Survivors are likely to have sustained penetrating chest injury with short down time. There is only one published survivor of PHRT following blunt trauma, despite this, PHRT is still being performed in the UK for this indication.

Keywords Pre-hospital · Resuscitative thoracotomy · Traumatic cardiac arrest · Penetrating chest trauma · Blunt chest trauma

Introduction

Resuscitative thoracotomy (RT) is now a recognized procedure for patients who are in extremis following traumatic cardiac arrest [1–4]. The primary objective of RT is to control and maintain perfusion to the cardio-respiratory and central nervous system. This can be achieved by the relief of tension pneumothorax, pericardiotomy for the relief of tamponade and cessation of cardiac haemorrhage, control of thoracic exsanguination, open cardiac massage, expulsion of massive air embolism, and temporary occlusion of the descending thoracic aorta for control of sub-diaphragmatic haemorrhage and redistribution of blood to supra-diaphragmatic organs [1, 3, 5].

Typically, this is performed in the emergency department (emergency department thoracotomy, EDT) as soon as possible after the patient arrives, as prognosis strongly correlates with the time between loss of cardiac output and commencement of this procedure [2]. In light of this, a number of authors have advocated that RT should not be performed if the patient has been in cardiac arrest for prolonged lengths of time [1–4]. Given that, advanced surgical skill and equipment is not always required for RT [6], pre-hospital resuscitative thoracotomy (PHRT) has, therefore, been considered as a viable option for patients who have arrested

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following trauma, and where there is prolonged transport time to hospital.

The first recorded PHRT was performed on a kitchen table in Alabama in 1902 by Dr Luther Leonidas Hill, who repaired a cardiac wound for a youth who had been stabbed in the chest, and the patient survived [7]. Despite this, over 100 years ago, there are still no globally accepted indications and contraindications for PHRT. In 2003, a USA publication by Hopson et al. stated that "thoracotomy is outside the remit of pre-hospital care" [8], and is, therefore, not advocated in the USA. Contrarily, PHRT has been practised by doctors onboard London UK Helicopter Emergency Medical Service (HEMS) since 1993 [7], and is readily practiced throughout Europe.

This study aims to review the published PHRT literature; specifically aiming to explore the outcomes of PHRT in the setting of penetrating and blunt trauma, and assess the current variation in practice across the UK and the world.

Methods

MEDLINE, PUBMED and EMBASE search engines were used to identify all relevant articles. Search terms employed included "emergency", "thoracotomy", "cardiac", "arrest", "resuscitation", "pre-hospital", "field", "roadside", in both exploded and linked combinations. The reference lists of all relevant articles were analysed to ensure none were missed. Publications were included which presented data on PHRT. Publications that presented data regarding EDT or non-urgent thoracotomy were excluded. Abstracts without full articles were also excluded.

To ascertain the current UK practice for PHRT, an electronic survey was sent to each air-ambulance service. This questioned their criteria for PHRT. A copy of the questionnaire can be seen in "Appendix 1".

Results: The literature review

PHRT for penetrating trauma

Twelve published articles which detail PHRT were identified. These include six case reports published between 1994 and 2007 (Table 1), of which, four are from the UK, one is from Spain and one is from the USA. All PHRTs described were performed by medically trained personnel; two by emergency physicians, one by an anaesthetist, one by a general surgical trainee, and three by doctors whose sub-speciality was unspecified. All patients were male, aged 50 years or less, and had sustained stab wounds to the chest. The time taken for medics to arrive on scene ranged from 7 to 15 min, time spent on scene time was 18–31 min, and time for transport to the nearest hospital ranged from 2 to 20 min.

The most common indication for PHRT in these case reports was an anticipated prolonged journey time to hospital for a patient in traumatic cardiac arrest (four patients) [9–12]. One patient underwent PHRT because they had had a down time of at least 7 min by the time the medic arrived, even though the hospital transfer time was only 2 min [13]. Five of the six patients were found to have tamponade during PHRT. All patients survived, with no recorded, or minimal, neurological deficit.

Five articles reported clinical case series, describing PHRTs performed in UK, Japanese and Dutch populations between 1993 and 2016 (Table 2). In total, they include 208 patients (however, the London case series study periods overlap, with some duplication of entries). Where reported, the average patient age was less than 45 years. Only one paper details the mean time spent on scene, which was 31.7 min [7]. Patients were transported back to hospital using a mix of ground and air ambulances. Two papers reported mean patient transport time to hospital as 9.29 and 12.5 min [7, 14].

As with all of the case reports, in all of the four European case series, PHRT was performed only for penetrating chest injury. The maximum proportion of survivors to discharge was 18.3% (13/71) [15]. A clamshell thoracotomy technique was used for all the London PHRTs, and all but four of the Dutch PHRTs, where an antero-lateral approach was used instead [16, 17].

PHRT for blunt trauma

The aforementioned paper from Japan, described PHRT being performed for blunt injury, from which there were no survivors to discharge from hospital, although 26.4% (9/34) of patients survived to reach the ITU (intensive therapy unit). Of note, where cardiac arrest occurred after the arrival of the emergency medical team, the survival to ITU rate was 70% (7/10), versus 8% (2/24) where cardiac arrest occurred prior to arrival of the team [18]. In this Japanese cohort, a left anterio-lateral approach, rather than clamshell method, for PHRT was used. A single publication has reported a survivor of PHRT for blunt trauma, however, the exact details of this patient are not published [19].

Results: survey of current PHRT practice by UK pre-hospital teams

Ten UK Air Ambulance Services responded to our survey: Devon, East Anglian, Hampshire and Isle of White, London, Cornwall, Great Western, Magpas, Midlands, and Kent, Surrey and Sussex. All ten pre-hospital teams practise

Table 1 Case reports of PHRT survivors

Paper	Location	Patient	Sub-speciality of physician	Medical transport time (mins)	Injury sustained	Patient condition on arrival	Time spent on scene (mins)	Estimated transport time (mins)	Findings of PHRT	Reason for PHRT	Outcome
Wright and Murphy [24]	London, UK	Teenage male	Medical team doctor	15	Stab to anterior left chest	Agonal breathing then cardiac arrest	18	4	Tamponade	Massive haemothorax found on thoracostomy	Survived, no neurological deficit
Wall et al. [12]	Texas, USA	30-year-old male	General surgical trainee	7	4 inch stab to left chest	Apnoeic with HR > 140 BPM	Not stated	15–20	2 L of blood in chest, no obvious source	Patient arrested and prolonged journey time	Survived, no neurological deficit
Keogh and Wilson [9]	London, UK	34-year-old male	HEMS doctor	10	Two stabs to anterior left chest	Two weak breaths then cardiac arrest	> 20	15	Tamponade with 1.5 cm right ventricular laceration	Patient arrested and prolonged journey time	Survived, no neurological deficit
Deakin [10]	Winchester, UK	50-year-old male	Medical ambulance doctor	11	Stab to lateral left chest	Cardiac arrest with agonal ECG rhythm	31	20	Tamponade and haemothorax	Patient arrested and prolonged journey time	Survived, now able to live independently
Craig et al. [13]	London, UK	Middle-aged male	Anaesthetist	14	Stab to chest*	Cardiac arrest	22	2	Tamponade with ventricular laceration	Patient arrested	Survived, no neurological deficit
Corral et al. [11]	Madrid, Spain	Young male	Emergency doctor	7	Several stabs to chest*	Cardiac arrest	> 13	> 10	Tamponade	Patient arrested and prolonged journey time	Survived, no neurological deficit

*Anatomical location not specified

Table 2 Papers demonstrating case series of PHRT

Paper	Location	Number of PHRTs performed	Dates included	Number of males (%)	Age (years)	Number of survivors to discharge (%)	Transport time to patient (mins)	Method of transport to patient	Method of transport to hospital
Athanasiou et al. [7]	London, UK	31	1994–2002	41* (77.3)	Mean 36.7*	3 (9.7)	Mean 9.29*	**	**
Davies and Lockey [15]	London, UK	71	1993–2008	**	**	13 (18.3)	**	Air or road	Air or road
Coats et al. [14]	London, UK	39	1993–1999	35 (89.7)	Mean 45	4 (10.3)	Mean 12.5	Air or road	Air or road
Matsumoto et al. [18]	Chiba, Japan	34	2003–2008	22 (64.7)	Median 35.7	0 (0)	**	Air	Air
Van Vledder et al. [17]	Holland	33	2011–2016	**	Median 38† and 31††	1 (3)	**	Air or road	**

*Corresponds to all patients in the study undergoing RT ($n=53$)

**Data not specified in paper

†For those sustaining stab wound

††For those sustaining gunshot wound

PHRT, and all have an agreed standard operating procedure. Reported indications and contraindications for PHRT from eight of the services can be seen in Tables 3 and 4.

Seven services reported that PHRT was performed in the setting of blunt trauma despite the lack of published evidence for doing so. Two of seven reported that they used ultrasound scan (USS) to aid their decision-making in this setting, for example, looking for evidence of pericardial effusion as justification for performing PHRT. Only five of the nine services who responded to the question regarding prehospital blood products actually carry them.

Discussion

There remain no accepted international guidelines for the indications and contraindications for PHRT. There is, however, strong evidence demonstrating an inverse correlation between survival and length of time of cardio-respiratory arrest prior to RT [20–22]. Moreover, external cardiac massage, as a temporising measure, is unlikely to be successful if a patient has an empty heart due to hypovolaemia, or cardiac tamponade [23]. Therefore, in the setting of traumatic cardiac arrest, PHRT may result in the only chance of survival for a small number of patients, where there is significant transport time to hospital.

PHRT for penetrating trauma

We have identified six case reports of successful PHRT, all performed in the setting of a stab wound to the chest. In five of the six cases, cardiac arrest had occurred in the setting of cardiac tamponade [9–11, 13]. Wall et al. report a case of PHRT following a thoracic stab wound, which resulted in the patient losing 2 L of blood into their thoracic cavity. The patient was successfully resuscitated following digital occlusion of their descending thoracic aorta [12], demonstrating that hypovolaemia may also be amenable to intervention by PHRT.

Wright et al. argue that PHRT should be reserved for patients with likely cardiac tamponade and stated a non-expert should not attempt the procedure. Importantly, they note that their patient awoke immediately after the release of his tamponade, highlighting that PHRT practitioners also need to be familiar with sedative and paralysing agents, in the event of there being return of spontaneous circulation (ROSC) and patient awareness [24]. All of the case reports examined suggest that PHRT should only be performed in the event of there being a correctable penetrating thoracic aetiology for the traumatic cardiac arrest, such as cardiac tamponade, localised cardiac injury or massive haemorrhage that could be controlled with thoracic aorta occlusion or cross-clamping. As the incidence of penetrating trauma is increasing, with a noticeable rise in the number of stab wounds to the thorax within the UK [7, 25], PHRT will inevitably result in further survivors.

We have identified a further five articles which present case series of PHRT (see Table 3). Athanasiou et al. reported three survivors in a group of ten patients who underwent PHRT for penetrating chest truama [7]. They note that there was no significant difference in survival rates where a thoracotomy (both PHRT and EDT) was performed by non-surgeons (anaesthetists and emergency physicians) when compared to surgeons, or when the procedure was undertaken by

Table 3 Reported indications and contraindications for PHRT by UK Air Ambulance Services

	Indications	Contraindications
1	Potentially salvageable traumatic cardiac arrest Penetrating chest/epigastric injury, loss of SOL < 15 min Witnessed cardiac arrest following blunt injury Peri-arrest and likely to progress to arrest before the patient can reach hospital despite maximal therapy	None survivable co-existing injury (e.g., obvious head injury) Confirmed cardiac arrest for > 20 min unless low cardiac output state suspected More than one eligible patient at scene Blunt trauma with > 30 min from MTC
2	Penetrating injury to chest or abdomen likely to have entered thoracic cavity causing arrest only Operator must demonstrate surgical skill annually to MD Loss of SOL < 10 min	Procedure currently suspended Blunt trauma
3	TCA secondary to penetrating injury within 10 min of arrest Witnessed TCA following blunt trauma	> 10 min of cardiac arrest
4	TCA with penetrating wounds from sternal notch to umbilicus or between scapula, loss of SOL < 15 min	Loss of SOL > 15 min prior to arrival of team Note this a Dr only skill
5	Absolute: Penetrating injury to chest, abdomen, neck, axilla or groin resulting in cardiac arrest or an agonal state (dilated pupils, Cheyne–Stokes respiration, absent/ barely palpable central pulse) Relative: Penetrating limb injury causing cardiac arrest, where immediate control of bleeding or vascular access cannot be established Cardiac arrest following blunt trauma where there were recent confirmed SOL	Multiple critically injured patients with resource limitations
6	Penetrating chest injury with < 15 min loss of SOL, though this can be EtCO2 compatible with low cardiac output state Penetrating abdominal injury Blunt trauma for witnessed cardiac arrest, as long as able to get patient to MTC within 25 min	Blunt cardiac arrest for > 15 min Penetrating cardiac arrest for > 15 min, or 30 min in cases where low cardiac output state is suspected
7	Penetrating chest injury resulting in cardiac arrest within 15 min of SOL	> 15 min from loss of SOL
8	Penetrating chest/abdomen injury resulting in witnessed cardiac arrest or loss of SOL within 10 min Blunt trauma resulting in cardiac arrest is not an absolute contraindication but each case must be given careful consideration	> 10 min of loss of SOL

SOL Signs of life

Table 4 Reported contraindications of PHRT by UK Air Ambulance Services

Contraindication	$n=9$
Massive traumatic brain injury	7
Time since cardiac arrest	7
Time to Major trauma centre	2
Blunt trauma	3
Extreme patient age	1
Multiple critically injured patients resulting in resource limitations	4

training grade doctors rather than consultants, emphasising the relative simplicity of the procedure. A non-statistically significant trend was demonstrated toward better survival in EDT patients compared to patients undergoing PHRT. However, the paper does not differentiate the patients' injury severity scores, which will inevitably be higher in patients requiring PHRT. For both EDT and PHRT patients, the median time of arrival of medics was 8 min, and median time spent at the scene was 17 min [7].

Coats et al. explore a case series of 39 PHRTs [14]. ROSC was achieved in 59% of patients, with 10% surviving to hospital discharge, of which 75% had no neurological deficit. Non-surgeons (anaesthetists and emergency physicians) performed 36 of the 39 procedures, including on all four of the survivors to hospital discharge. All survivors sustained stab wounds, had cardiac tamponade with a single cardiac lesion, and had signs of life witnessed in the field following the injury [14]. Multiple reviews have stated that loss of signs of life prior to arrival at hospital correlates with poor survival in EDT [1–3, 26]. It is conceivable that the patients that survived after undergoing a PHRT in this series would not have survived a delay in treatment with an EDT [14].

Davies and Lockey add to data from Coates et al. [15]. In total, they report 13 survivors from 71 PHRTs, again all of whom were found to have tamponade. Ten of the survivors were neurologically intact, and those that were not had greater than 5 min of down time prior to arrival of the

pre-hospital team. There were no survivors of gunshot injuries, although they did not report the number of PHRTs performed in this group. The authors recommend that the goal of PHRT should be the relief of tamponade, and that exsanguination is not amenable to pre-hospital treatment [15].

Van Vledder et al. review 33 PHRTs [17]. Fourteen of these cases were performed by surgeons, with the remainder being performed by anaesthetists. 27% of patients had ROSC, however, only three survived to ITU, and only one to hospital discharge; again, a patient who had tamponade secondary to a stab wound. Fourteen additional patients with tamponade did not survive. All ten patients sustaining gunshot wounds did not survive. Seven of the 33 PHRTs were performed greater than 10 min after cardiac arrest (which is a widely accepted contraindication to the procedure), and, unsurprisingly, none of this group survived. This would advocate stricter adherence to PHRT exclusion criteria.

London HEMS recommends that PHRT should not be taught to paramedics [14, 15]. Other authors have advised that PHRT does not require detailed knowledge of cardiothoracic surgery,[7, 11] or specialist equipment,[6] and adequate training can be achieved during short courses [17, 27, 28]. Ashrafian and Athansiou even describe methods for PHRT in the absence of specialist equipment, encouraging the use of an L-shape thoracotomy or thoraco-sterno-costochondrotomy [6]. Furthermore, delay to definitive treatment reduces survival [8, 21, 22]. This suggests that, if indicated, PHRT should be performed as soon as a person with adequate training in the procedure arrives on scene.

PHRT for blunt trauma

Historically, the survival rates of EDT following blunt trauma are poor [1–3]. Powell and colleagues demonstrated that thoracotomy is futile following blunt trauma if CPR has been continued for longer than 5 min [29]. However, there are survivors of EDT noted in patients sustaining blunt or non-thoracic injury—therefore, arguably, patients with these injury patterns should be considered for PHRT, if they cannot be transported and receive more definitive surgical intervention within 5 min [1, 3].

In Japan, PHRT is performed for blunt causes of traumatic cardiac arrest [18]. This practice has also been adopted by Australian pre-hospital teams [30, 31], and is now practiced in the UK [19, 32]. Matsumoto et al. report that the procedure is performed in patients with blunt traumatic cardiac arrest, with the aim of aortic cross-clamping [18]. This suggests that PHRT may have a role in management of the exsanguinating patient. PHRT has also been performed in Holland following blunt trauma, but has not demonstrated any survivors [17]. Matsumoto and colleagues report 81 patients who sustained cardiac arrest in the field secondary to blunt trauma. Fifty-two arrested prior to arrival of the emergency medical technician (be that doctor or paramedic) and 29 arrested after this point. 34 of 81 patients underwent PHRT, a further 10 did not have PHRT (despite a medic being present in the field) and subsequently underwent EDT, and 37 had an EDT (as no medic was present in the field to perform PHRT) [18]. Despite no patients in this series surviving to hospital discharge, eight of ten patients who arrested after the arrival of a medic regained cardiac output following PHRT, and seven survived to ITU. Only 2 of 24 patients who arrested prior to the arrival of a medic regained cardiac output following PHRT, but both also made it to ITU. All of the patients later died in ITU, secondary to coagulopathy, neurological injury, severe chest injury, or major haemorrhage. The PHRTs themselves, however, were deemed a success [18]. This implies that improvement in ITU care could result in better outcomes for a blunt trauma patient post PHRT.

Matsumoto et al. report that the mean time to arrival of medics at the scene was 7 min in the PHRT group [18]. EDT data suggest that patients will inevitably die if RT is performed following greater than 5 min of down time, so if time to procedure is expedited this could result in greater rates of survival to discharge for the blunt trauma patient. Importantly, the authors also demonstrate that where PHRT was not performed, having a doctor on scene significantly reduced time to EDT being done (21.3 vs. 30.7 min), suggesting that doctors have an important role in terms of clinical decision-making, not just in simply performing the PHRT procedure [18].

A single publication reports a survivor of PHRT for blunt trauma, however, the exact details of this patient are not published [19]. Nor does this paper publish the number of failed PHRT for blunt trauma.

Future direction of PHRT in the UK

Our survey of UK Air Ambulance Services confirms that PHRT is being performed for both blunt and penetrating trauma in the UK, despite the poor outcomes that have been published for PHRT for blunt trauma patients; with only a single survivor to hospital discharge in the published literature. Moreover, we have identified that contraindications for PHRT vary substantially between air ambulance services across the UK. There is some ambiguity regarding the timeframe within which PHRT should be considered futile. Though most UK Air Ambulance Services indicated that they would not advocate PHRT if more than 10 or 15 min had elapsed since loss of signs of life.

Low cardiac output states may be difficult to differentiate from true loss of signs of life especially within the pre-hospital setting, therefore, utilisation of "time from loss of signs of life", as a strict contraindication for PHRT, may not be appropriate. Recently, pre-hospital USS has been used to

aid decision-making when the patient does not fit the normal criteria for PHRT, despite there being no published data for this. This modality is particularly useful for demonstrating cardiac tamponade, or low cardiac output states due to hypovolaemia, versus true cardiac arrest [30, 33]. Indeed, the Sydney and Queensland Ambulance Services advocate that PHRT following blunt trauma should be reserved for those patients with USS confirmed pericardial tamponade [31]. USS has also been shown to be useful in the identification of potential survivors of traumatic cardiac arrest in the emergency department setting, where the likelihood of survival of EDT is low in the absence of a potentially reversible cause, such as tamponade, or cardiac motion [34].

Only five of nine HEMS regions surveyed carry transfusion products, and therefore, concurrent damage control resuscitation (DCR) is not possible without these, which is likely to result in failure of PHRT, in the extensively injured blunt trauma patient. Our experience is that patients, who experience blunt traumatic cardiac arrest, require extensive surgical intervention with concurrent DCR and massive transfusion.

Conclusions

PHRT is a potentially life-saving procedure for the arrested trauma patient. It was first performed with success over 100 years ago, but there is still no consensus on its exact indications. Current indications for PHRT vary amongst geographical locations, across both the UK and the rest of the world. We recognise that those who are most likely to survive this procedure have a short down time secondary to penetrating chest injury. We still do not know for certain if PHRT should have a role following blunt traumatic cardiac arrest. However, improved post-procedure care, and quicker medical on scene arrival, may result in patients who survive to discharge following PHRT for blunt trauma.

It could be argued that if a pre-hospital team witnesses a cardiac arrest secondary to trauma, or arrives within 5 min of it occurring, that PHRT should be performed immediately, regardless of the mechanism of injury, as long as the pre-hospital team is adequately trained, and that concurrent DCR is initiated. This may provide a good outcome in a small number of patients who would otherwise not survive. What is clear is that the clinical decision-making and practical skills pertaining to PHRT are time-critical, and may result in the resuscitation of an otherwise unsalvageable casualty.

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Compliance with ethical standards

Conflict of interest The authors have no conflicts of interest to declare.

Appendix 1

1. Does your service practice pre-hospital resuscitative thoracotomy?
2. Do you have a standard operating procedure for PHRT?
3. What are your indications for performing PHRT?
4. What are your exclusion criteria for performing PHRT?
5. Do you perform PHRT following blunt trauma?
6. Do you use ultrasound to aid decision-making for PHRT following blunt trauma?
7. Does your service carry pre-hospital blood and blood products?

References

1. 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.
2. "Practice management guidelines for emergency department thoracotomy. Working group, Ad Hoc subcommittee on outcomes, American College of Surgeons-Committee on Trauma. J Am Coll Surg. 2001;193(3):303–9.
3. Cothren CC, Moore EE. Emergency department thoracotomy for the critically injured patient: objectives, indications, and outcomes." World J Emerg Surg. 2006;1:4.
4. Seamon MJ, Haut ER, Van Arendonk K, Barbosa RR, Chiu WC, Dente CJ, Fox N, Jawa RS, Khwaja K, Lee JK, Magnotti LJ,, Rowell S, To KB, Falck-Ytter Y, Rhee P, Mayglothling JA, McDonald AA. An evidence-based approach to patient selection for emergency department thoracotomy: a practice management guideline from the Eastern Association for the Surgery of Trauma. J Trauma Acute Care Surg. 2015;79(1):159–73.
5. Hunt PA, Greaves I, Owens WA. Emergency thoracotomy in thoracic trauma—a review. Injury. 2006;37(1):1–19.
6. Ashrafian H, Athanasiou T. Emergency prehospital on-scene thoracotomy: a novel method. Coll Antropol. 2010;34(4):1449–52.
7. Athanasiou T, Krasopoulos G, Nambiar P, Coats T, Petrou M, Magee P, Uppal R. Emergency thoracotomy in the pre-hospital setting: a procedure requiring clarification. Eur J Cardio Thoracic Surg. 2004;26(2):377–85.
8. Hopson LR, Hirsh E, Delgado J, Domeier RM, McSwain NE, Krohmer J, Weldon C, Friel M, Hoyt DB. Guidelines for withholding or termination of resuscitation in prehospital traumatic cardiopulmonary arrest. J Am Coll Surg. 2003;196(3):475–81.
9. Keogh SP, Wilson AW. Survival following pre-hospital arrest with on-scene thoracotomy for a stabbed heart. Injury 1996;27(7):525–7.
10. Deakin CD. From agonal to output: An ECG history of a successful pre-hospital thoracotomy. Resuscitation 2007;75(3):525–9.

11. Corral E, Silva J, Suarez RM, Nunez J, Cuesta C. A successful emergency thoracotomy performed in the field. Resuscitation 2007;75(3):530–3.
12. Wall MJ, Pepe PE, Mattox KL. Successful roadside resuscitative thoracotomy: case report and literature review. J Trauma. 1994;36(1):131–4.
13. Craig R, Clarke K, Coats TJ. On scene thoracotomy: a case report. Resuscitation 1999;40(1):45–7.
14. 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.
15. Davies GE, Lockey DJ. Thirteen survivors of prehospital thoracotomy for penetrating trauma: a prehospital physician-performed resuscitation procedure that can yield good results. J Trauma. 2011;70(5):E75–E78.
16. Wise D, Davies G, Coats T, Lockey D, Hyde J, Good A. Emergency thoracotomy: 'how to do it'. Emerg Med J. 2005;22(1):22–4.
17. Van Vledder MG, Van Waes OJF, Kooij FO, Peters JH, Van Lieshout EMM, Verhofstad MHJ. Out of hospital thoracotomy for cardiac arrest after penetrating thoracic trauma. Injury. 2017;48(9):1865–9.
18. Matsumoto H, Mashiko K, Hara Y, Kutsukata N, Sakamoto Y, Takei K, Kanemaru K, Tomita Y, Saito N, Yagi T, Tetsu S, Iida H, Masuda Y, Koami H, Yokota H. Role of resuscitative emergency field thoracotomy in the Japanese helicopter emergency medical service system. Resuscitation. 2009;80(11):1270–4.
19. Lockey D, Crewdson K, Davies G. Traumatic cardiac arrest: who are the survivors?" Ann Emerg Med. 2006;48(3):240–4.
20. 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.
21. Durham LA, Richardson RJ, Wall MJ, Pepe PE, Mattox KL. Emergency center thoracotomy: impact of prehospital resuscitation. J Trauma. 1992;32(6):775–9.
22. Schwab CW, Adcock OT, Max MH. Emergency department of thoracotomy (EDT). A 26-month experience using an 'agonal' protocol. Am Surg. 1986;52(1):20–9.
23. Luna GK, Pavlin EG, Kirkman T, Copass MK, Rice CL. Hemodynamic effects of external cardiac massage in trauma shock. J Trauma. 1989;29(10):1430–3.
24. Wright K, Murphy K. Cardiac tamponade: a case of kitchen floor thoracotomy. Emerg Med J. 2002;19:587–88.
25. Crewdson K, Lockey D, Weaver A, Davies GE. Is the prevalence of deliberate penetrating trauma increasing in London? Experiences of an urban pre-hospital trauma service Injury. 2009;40(5):560–3.
26. Dayama A, Sugano D, Spielman D, Stone ME, Kaban J, Mahmoud A, Mcnelis J. Basic data underlying clinical decision-making and outcomes in emergency department thoracotomy: tabular review. ANZ J Surg. 2016;86(1–2):21–6.
27. The Royal College of Surgeons of England, Pre-hospital and emergency department resuscitative thoracotomy (PERT). 2017. https://www.rcseng.ac.uk/education-and-exams/courses/search/prehospital-and-emergency-department-resuscitative-thoracotomy-pert/. Accessed 28 Dec 2017.
28. Harrison OJ, Lockey D. Should resuscitative thoracotomy be performed in the pre-hospital phase of care?" Trauma. 2013;15(2):176–85.
29. Powell DW, Moore EE, Cothren CC, Ciesla DJ, Burch JM, Moore JB, Johnson JL. 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.
30. Sherren P, Reid C, Habig K. Algorithm for the resuscitation of traumatic cardiac arrest patients in a physician-staf ed helicopter emergency medical service. Crit Care. 2013;17:S105–6.
31. Clinical Quality and Patient Saftey Unit, Clinical practice procedures: trauma/thoracotomy. 2016. https://www.ambulance.qld.gov.au/docs/clinical/cpp/CPP_Thoracotomy.pdf. Accessed 28 Dec 2017.
32. Lockey DJ, Brohi K. Pre-hospital thoracotomy and the evolution of pre-hospital critical care for victims of trauma. Injury. 2017;48(9):1863–4.
33. Smith JE, Rickard A, Wise D. Traumatic cardiac arrest. J R Soc Med. 2015;108(1):11–6.
34. Inaba K, Chouliaras K, Zakaluzny S, Swadron S, Mailhot T, Seif D, Teixeira P, Sivrikoz E, Ives C, Barmparas G, Kornakis N, Demetriades D. FAST ultrasound examination as a predictor of outcomes after resuscitative thoracotomy. Ann Surg. 2015;262(3):512–8.