Out of Hospital Thoracotomy for Cardiac Arrest after Penetrating Thoracic Trauma

Implementation and outcomes in a physician staffed HEMS operation

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Abstract

Introduction: Emergency department thoracotomy is an established procedure for cardiac arrest in patients suffering from penetrating thoracic trauma and yields relatively high survival rates (up to 21%) in patients with cardiac tamponade. To minimize the delay between arrest and thoracotomy, some have advocated thoracotomy on the accident scene. The aim of this study was to determine the proportion of patients with return of spontaneous circulation and subsequent survival after out of hospital thoracotomy in the Netherlands.

Methods: A retrospective analysis of data collected on all out of hospital thoracotomies performed in the Netherlands after penetrating trauma between April 1st, 2011 and September 30th, 2016 was performed. Data on patient characteristics, trauma mechanism and outcome were collected and analyzed. Primary outcome measure was return of spontaneous circulation after the intervention. Survival to hospital discharge was the secondary outcome variable.

Results: Thirty-three prehospital emergency thoracotomies were performed. Ten patients (30%) had gunshot wounds and 23 patients (70%) had stab wounds. Nine patients (27%) had return of spontaneous circulation and were presented to the hospital. Of these, one patient survived until discharge without neurological damage. Five died in the emergency department or operating room and three died in ICU.

Conclusion: Return of spontaneous circulation after out of hospital thoracotomy for cardiac arrest due to penetrating thoracic injury is achievable, but a substantial number of patients die during the in hospital resuscitation phase. However, neurologic intact survival can be achieved.

Introduction

Traditional cardiopulmonary resuscitation for out of hospital traumatic cardiac arrest is associated with poor survival [1]. For patients with cardiac arrest resulting from cardiac tamponade after penetrating thoracic injury, emergency thoracotomy with decompression of the pericardial sac may offer a significant chance of survival. Emergency department series have reported survival rates up to 21% [1].

Emergency department thoracotomy has been included in the guidelines of the European resuscitation council as a resuscitative procedure for patients suspected of having circulatory arrest and cardiac tamponade [2]. Emergency room thoracotomy has been an established procedure in Dutch trauma centers for many years with favorable results [3]. Longer transportation times to the hospital may be associated with poor outcome in these patients; Ideally thoracotomy should be performed within 10 minutes after circulatory arrest, which is very hard to achieve when arrest occurs in an out of hospital setting[1]. Davies *et al*. reported on prehospital thoracotomies performed by the physician-led London Helicopter Emergency Medical Service (HEMS) in patients suffering from cardiac arrest after sustaining a stab wound to the chest. Thirteen out of 71 patients survived to hospital discharge after out of hospital emergency thoracotomy [4]. Therefore, it was hypothesized that adding this procedure to the armamentarium of Dutch HEMS personnel may lead to increased odds of survival in selected patients.

The aim of this retrospective case-series was to determine the proportion of patients with return of spontaneous circulation and subsequent survival after out of hospital thoracotomy.

Furthermore, we describe the introduction and implementation of this procedure in the Dutch physician staffed Helicopter Emergency Medical Service (HEMS).

Methods

Dutch HEMS operation

The Netherlands covers approximately 41,000 square kilometers and holds about 17 million inhabitants. Prehospital emergency medical services are mostly provided by ground ambulance crews staffed with paramedics, trained in prehospital trauma life support (PHTLS) and a background in intensive care or emergency medicine. Ground emergency medical services (EMS) are supplemented by four physician-led HEMS operations across the country. A HEMS team consists of a board-certified anesthesiologist or trauma surgeon, a specialized nurse, and a helicopter pilot. The primary purpose of the Dutch HEMS operation is to provide specialized medical care on scene, including advanced airway management and specific procedures such as thoracostomy and chest tube drainage.

Three of four Dutch HEMS operations implemented prehospital thoracotomy and participated in this study. The fourth HEMS station is located in a largely rural environment in which penetrating thoracic injury due to gunshot or stab wounds is less frequently encountered and have not yet introduced this procedure into their practice.

Training for out of hospital thoracotomy

In order to familiarize HEMS crew members with the procedure of emergency thoracotomy, physicians and nurses received theoretical and practical training by board certified trauma surgeons with extensive experience in emergency department thoracotomy. First, the available protocols and literature with regard to indications and outcomes for resuscitative thoracotomy were discussed. Thereafter, the anatomy of the thoracic wall and mediastinum were reviewed thoroughly and the technique for anterolateral and clamshell thoracotomy was

described. Finally, skills were extensively and repeatedly trained in the cadaver lab on fresh frozen cadavers (Figure 1).

Indications, technique and equipment

During in-hospital resuscitation on a stretcher or operating table at near eye level, a left anterolateral thoracotomy provides sufficient access to the mediastinum to open the pericardium and decompress cardiac tamponade. In the prehospital setting, a clamshell thoracotomy is preferred as this provides optimal exposure for the supine patient on the ground. The procedure is relatively easy to perform and allows for treatment of various traumatic injuries, even for non-surgical personnel [5]. Indications and technique are strictly protocolled and modeled on the recommendations of Wise *et al.* [6]. In short, thoracotomy is performed in all patients with (1) penetrating thoracic injury or upper abdominal injury with suspected cardiac tamponade, (2) a delay shorter than 10 minutes between cardiac arrest and arrival of the HEMS crew or signs of life (pupil reflexes, gasping or ECG activity) at arrival of the HEMS crew, (3) no other non-survivable injuries and (4) the inability to transport the patient to an ER equipped for thoracotomy within 10 minutes of cardiorespiratory arrest.

After the HEMS crew and EMS personnel agree on the indication for out of hospital thoracotomy, the patient is placed in supine position, asepsis is applied and bilateral thoracostomies are created in the 5th intercostal space in the mid-axillary line to exclude a tension pneumothorax as a possible cause for arrest. If circulation does not recover, both thoracostomies are connected resulting in a clamshell thoracotomy. A Finochietto rib-spreader is used for permanent exposure. After opening the thorax and pericardium, fluids and clotted blood are removed and bleeding wounds in the heart are occluded with a finger, a balloon catheter or sutures (Figure 2). If the heart does not start beating spontaneously,

internal massage is attempted with additional procedures such as leg raise, prehospital blood transfusion or transthoracic defibrillation (if ventricular fibrillation occurs) at the discretion of the treating physician. When exsanguination from a source outside of the heart is encountered (lung, great vessels or below the diaphragm), hemostatic measures including lung twist or cross-clamping the aorta may be attempted. In case of return of spontaneous circulation (ROSC), standard post ROSC care is initiated and the patient is transferred to the nearest trauma center. If no ROSC is noted 15 min after opening of the pericardium further resuscitation is withheld.

Our thoracotomy kit contains the following instruments; 2 pair of protective goggles, 2 pair of surgical gloves, anti-septic solution, gauzes, five abdominal packs, two disposable scalpels (size 20), one pair of heavy scissors, two hemostatic clamps, two forceps, one pair of Metzenbaum scissors, a Gigli-saw, a Finocietto ribspreader, a needle holder, one double armed polypropylene 3-0 suture, a 6 Fr Foley Catheter and a skin stapler.

Data collection and statistical analysis

This study is a retrospective analysis of data collected between April 1st, 2011 and September 30th, 2016. Patients were identified by searching a a prospective database of patients undergoing out of hospital emergency thoracotomy. This was cross checked and supplemented by data from a computer database in which all Dutch HEMS dispatches are registered using the Dutch terms for “thoracotomy” and relevant synonyms. Missing data as well as data on in-hospital treatment and outcome were retrospectively acquired from the electronic patient files. The following variables were collected; age, gender, trauma mechanism, peri-arrest ECG rhythm, delay between cardiac arrest and thoracotomy, technique used to enter the thorax, injuries found after thoracotomy and outcome. Data were analyzed using the Statistical Package for the Social Sciences (SPSS) version 23.0 (SPSS, Chicago, Ill., USA). Missing values were not imputed. For continuous parametric data (*e.g.*, age) the mean and standard deviation, and for continuous non-parametric data the median and percentiles are reported. For categorical data (e.g., gender) numbers and frequencies are reported. The study protocol was approved by the Medical Research Ethics Committee of the coordinating center.

Results

A total of 33 out of hospital thoracotomies were performed. Fourteen thoracotomies (42%) were performed by five trauma surgeons and 19 thoracotomies (58%) were performed by eleven anesthesiologists. Patient characteristics and outcome are presented in table one, stratified by trauma-mechanism.

Zero out of ten patients with gunshot wounds had return of spontaneous circulation. Nine out of 23 patients with stab wounds (39%) had return of spontaneous circulation after thoracotomy on-scene and were presented to the hospital with spontaneous circulation (Figure 3). Of these, one patient (4%) survived neurologically intact to hospital discharge. Three patients died in the ICU (13%) among whom was one patient that died as a result of ongoing hemorrhage from a stab wound to the neck combined with severe coagulopathy. Two patients were found to have severe post-anoxic brain damage once in ICU and further treatment was withheld. Two patients (9%) succumbed in the ER due to ongoing hemorrhage from other penetrating injuries to superior vena cava injury and aorta respectively. Three patients (13%) died in the OR: One died due to exsanguination from a large right ventricle tear, another patient died due to cardiac failure resulting from right ventricle ischemia following traumatic transection of the right main coronary artery and the third patient died due to refractory cardiogenic shock after prolonged open chest cardiac massage.

The one surviving patient in this series was a 35-year-old man that sustained a stab wound just below the left nipple. On arrival of the ground EMS and HEMS crew within 10 minutes of the initial call, the patient was still conscious and had spontaneous circulation. The patient was urgently loaded into the ambulance. An ultrasound performed during transportation to

the nearest trauma center confirmed cardiac tamponade. Seconds after the diagnosis, the patient went into circulatory arrest. After tracheal intubation a left anterolateral thoracotomy was performed by the HEMS physician in the ambulance. The pericardial sac was opened and blood clots evacuated. The patient regained spontaneous circulation and there was profuse bleeding from a penetrating wound in the anterior side of the right ventricle which was successfully occluded with gentle finger pressure. Once in the hospital, the patient was urgently transferred to the OR where the perforation was sutured with minimal further blood loss. Apart from a slightly prolonged period of ICU admission due to pneumonia, the further course was uneventful. Nine days after hospital admission the patient was discharged home without any neurological impairment.

Provider Safety

Multiple glove tears with subsequent skin exposure to the patient's blood were reported (no complete data). Two HEMS physicians reported a superficial skin cut following scalpel injury during the prehospital surgery. In both cases, the patients' blood was found to be free of pathogens.

Discussion

This paper describes the introduction of prehospital emergency thoracotomy in the Dutch HEMS operation. A total of 33 prehospital emergency thoracotomies were performed in patients suffering cardiac arrest after sustaining penetrating thoracic injury. Nine patients had ROSC and one patient survived to hospital discharge. Since 59% of thoracotomies were performed by anesthesiologists (among which the only surviving patient in this series), we believe this procedure can be successfully taught to and safely performed by all Dutch HEMS physicians [7].

Outcomes in the current series are relatively poor when compared to the scarce data that is available on the subject. However, we believe this large consecutive case series to be an important addition to the existing literature, as it may provide important lessons for other pre-hospital services with regard to expected outcomes and potential pitfalls.

In 2001, Coats *et al.* reported on 34 patients in cardiac arrest after sustaining penetrating thoracic injury (gunshot or stab wound) undergoing out of hospital emergency thoracotomy of whom four patients survived (10%) [8]. Four years later, after excluding all patients that did not meet the very stringent inclusion criteria for their study, Davies *et al.* reported on 71 patients with a single stab wound to the chest and a delay of less than 10 minutes between arrest and thoracotomy. Thirteen patients survived (18%) [4]. From both series it is clear that patients with cardiac arrest due to a single stab wound to the chest and a short delay to thoracotomy have the best odds of survival. This notion is further supported by the fact that all available case series and case reports that document survival after out of hospital emergency thoracotomy pertain to patients with a single stab wound to the chest or epigastrium, a short delay to thoracotomy and cardiac tamponade upon opening the chest [6, 9,

[10]. Indeed, when we limit the current analysis to this group of patients with a single stab wound, short delay and cardiac tamponade, the survival rate in this series is one out of seven (14%).

Conversely, it is clear from the current series as well as other available data that patients going into cardiorespiratory arrest after sustaining gunshot wounds to the heart, patients with multiple gunshot or stab wounds, patients without signs of life after sustaining their injury and patients who arrest as a result of exsanguination do uniformly succumb when going into cardiac arrest in an out of hospital setting, even when on-scene emergency thoracotomy is performed. Withholding resuscitative thoracotomy in these patients remains a point of debate. Experience from ER thoracotomy has shown that even in these patients there is an –albeit small- chance of neurologically intact survival [3 1 11]. Since the available data on out of hospital emergency thoracotomy for pulseless patients with gunshot wounds to the chest is extremely limited, the first survivor may as well be expected.

Whether out of hospital thoracotomy should be performed in patients with cardiopulmonary arrest after blunt force trauma has not been addressed in the current study. Although some Dutch HEMS physicians have achieved return of spontaneous circulation in patients with a witnessed arrest after blunt trauma (but no survivors), we decided not to include these patients in the current study. A Japanese series reporting on 34 prehospital thoracotomies for blunt trauma did not identify any survivors in their cohort either[12].

Patient selection is probably the largest contributor to the poor overall results in this series. More stringent criteria will certainly lead to less futile thoracotomies, but may refute some patients a last chance of survival. Perhaps ultrasound may aid a better identification of

potential survivors, as a recent study showed that the absence of both cardiac motility and pericardial effusion on transthoracic ultrasound is associated with zero survivors [13]. On the other side, precious time may be lost while performing ultrasound which may even affect neurological outcome. Two other factors should be considered when evaluating the poor survival-rate in this study. First, as this is a novel procedure for most of Dutch HEMS physicians, many may not have reached the top of their learning curve for out of hospital emergency thoracotomy yet. Second, of the nine patients who had ROSC and made it to the hospital, eight succumbed in the ED, OR, or ICU. As these nine patients were admitted to seven different hospitals across the country, experience with patients presented after prehospital emergency thoracotomy is severely limited in most emergency departments. Better education and selection of receiving hospitals and the development of specific protocols for these patients may contribute to a higher rate of survivors in the near future.

Of the eight patients that made it to the hospital but did not survive until discharge, uncontrollable hemorrhage was the cause of death in four patients. Two patients died due to severe post-anoxic brain damage and two patients due to cardiac failure. Unfortunately, the exact cause of death in patients that did not make it to the hospital is unknown in the current series. Likely, the majority of these patients will have suffered from massive cardiac or intrapericardial great vessel injury, extrapericardial great vessel injuries, parenchymal lung injuries or mixed injuries with concomitant exsanguination. Indeed, a series from South Africa identified these injuries to be responsible for 50%, 22%, 15% and 13% of prehospital deaths resulting from penetrating thoracic trauma respectively [14].

One of the major concerns we had regarding the introduction of this procedure is provider safety. As a significant proportion of trauma victims may be carrier of blood borne

pathogens, this is a main concern[15]. Indeed, some have reported glove tears and two incidents were reported in which the HEMS physician sustained a penetrating finger injury. Luckily, no blood borne pathogens were detected in the trauma victims blood. Wearing double gloves and protective eye gear and incorporating the risk of incidents due to sharp needles, knives or fractured ribs in the team briefing should be standard of care.

Another concern is the psychological burden laid upon non-medical emergency providers personnel at the scene, since being confronted with an opened chest may be a traumatic experience. We recommend rapid pre-briefing and post-procedural debriefing. Additional support should be offered if needed.

In summary, out of hospital emergency thoracotomy for pulseless patients with penetrating thoracic injury was successfully implemented in the Dutch HEMS operation leading to return of spontaneous circulation after thoracotomy in 27% of patients and a first survivor. We therefore believe prehospital emergency thoracotomy is a feasible and justified resuscitative procedure in the trauma care system of the Netherlands. However, since out of hospital thoracotomy exerts certain risks for the healthcare providers and may be a traumatic experience for bystanders, exact indications and contra-indications should be an area of constant evaluation.

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Table one: Comparison of characteristics and outcome of patients undergoing pre-hospital thoracotomy for cardiac arrest following penetrating chest injury due to gunshot wounds and stab wounds.

	Stab wound N=23	**Gunshot wound N=10**
Age		
Median (SD)	38 (18)	31 (9)
Unknown	5	1
Delay between arrest and thoracotomy		
Witnessed	5 (22%)	2 (20%)
< 10 minutes	11 (48%)	3 (30%)
> 10 minutes	5 (22%)	2 (20%)
Unknown	2 (8%)	3 (30%)
Peri-arrest rhythm		
EMD	16 (70%)	3 (30%)
Asystole	6 (26%)	5 (50%)
Unknown	1 (4%)	2 (20%)
Other penetrating injuries		
None	19 (84%)	7 (70%)
Abdomen	1 (4%)	0
Head	0	2(20%)
Abdomen and neck	1 (4%)	1 (10%)
Extremity	2 (8%)	0
Technique		
Anterolateral	4 (17%)	0
Clamshell	19 (83%)	10 (100%)
Cardiac Tamponade		
Yes	14 (61%)	1 (10%)
No	9 (39%)	7 (70%)
Unknown	0	2 (30%)
Outcome		
Dead at the scene	14 (61%)	10 (100%)
Dead in ER	2 (9%)	0
Dead in OR	3 (13%)	0
Dead in ICU	3 (13%)	0
Survival to discharge	1 (4%)	0

Figure 1: Thoracotomy training in the cadaver lab on fresh-frozen body

Figure 2: On-scene clamshell thoracotomy

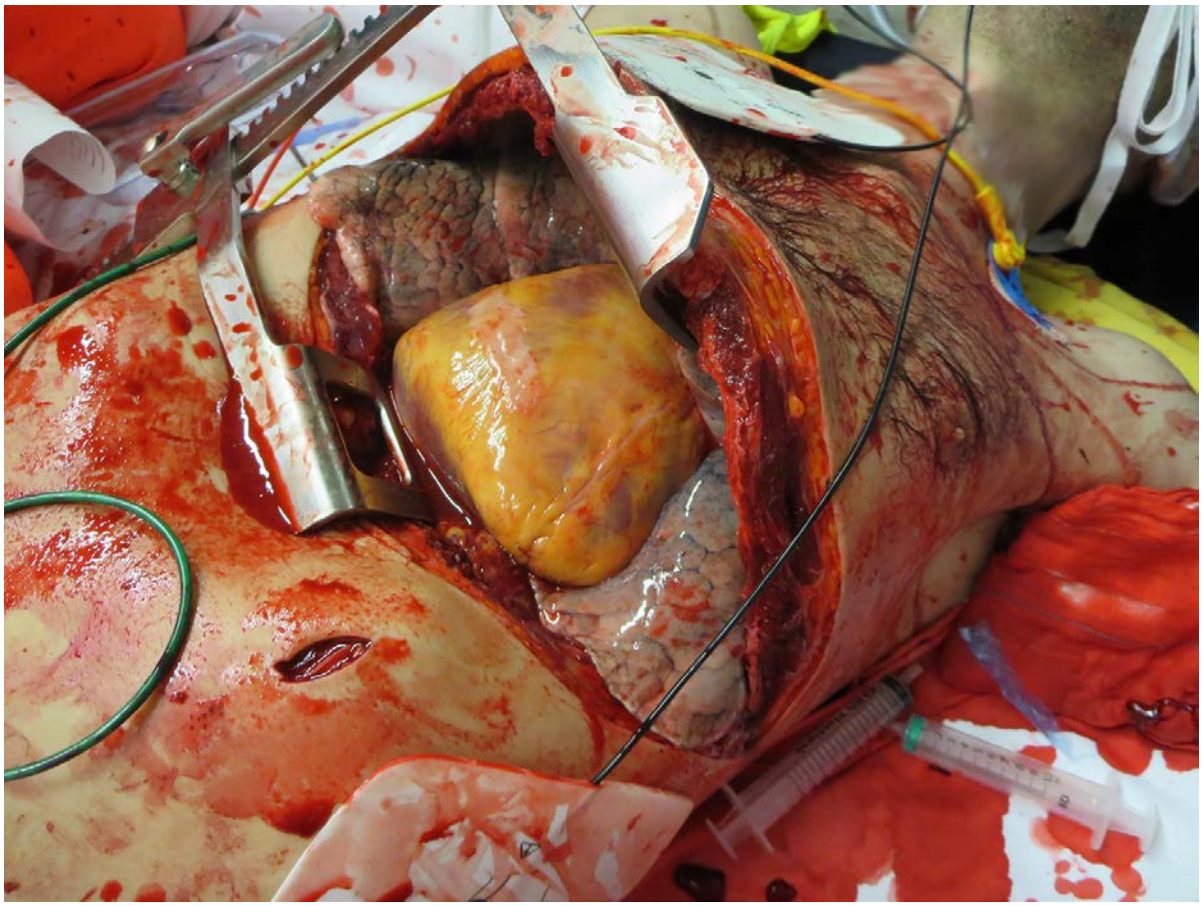

Figure 3: Flowchart with patient outcomes