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Original article

Thoracotomy in the emergency department for resuscitation of the mortally injured

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A R T I C L E I N F O

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Purpose: Emergency department resuscitative thoracotomy is an intervention of last resort for the acutely dying victim of trauma. In light of improvements in pre-hospital emergency systems, improved operative strategies for survival such as damage control and improvements in critical care medicine, the most extreme of resuscitation efforts should be re-evaluated for the potential survivor, with success properly defined as the return of vital signs which allow transport of the patient to the operating room.
Methods: A retrospective review of all patients at a suburban level I trauma center who underwent emergency department resuscitative thoracotomy as an adjunct to the resuscitation efforts normally delivered in the trauma receiving area over a 22 year period was performed. Survival of emergency department resuscitative thoracotomy was defined as restoration of vital signs and transport out of the trauma resuscitation area to the operating room.
Results: Sixty-eight patients were identified, of whom 27 survived the emergency department resuscitative thoracotomy and were transported to the operating room. Review of pre-hospital and initial hospital data between these potential long term survivors and those who died in the emergency department failed to demonstrate trends which were predictive of survival of emergency department resuscitative thoracotomy. The only subgroup which failed to respond to emergency department resuscitative thoracotomy was patients without signs of life at the scene who arrived to the treatment facility without signs of life.
Conclusion: The patient population of the “potential survivor” has been expanded due to advances in critical care practices, technology, and surgical technique and every opportunity for survival should be provided at the outset. Emergency department resuscitative thoracotomy is warranted for any patient with thoracic or subdiaphragmatic trauma who presents in extremis with a history of signs of life at the scene or organized cardiac activity upon arrival. Patients who have no evidence of signs of life at the scene and have no organized cardiac activity upon arrival should be pronounced.

Introduction

The ability to address life threatening injuries with a thoracic intervention began in 1897 when Rehn reported the first successful thoracotomy for a cardiac injury.[1] His subsequent review of the world's literature on cardiac injury treated with thoracotomy in 1907[2] reported a 58% mortality rate. This mortality rate remained unchanged through the beginning of the Second World War.[2–4] Those concerned about the high mortality associated with thoracotomy advocated pericardiocentesis. In spite of Streider's statement in 1939 that “not operating on a patient with a stab wound of the heart is a very hazardous course to follow”,[5] by 1943 pericardiocentesis was the standard of initial care for penetrating cardiac injury and remained so until 1957 when Lyons reported survival in 66 of 74 patients treated with thoracotomy.[6,7]

In 1961 Beall et al[8] reported cardiorrhaphy carried out in the emergency room, “frequently with survival of the patient”, and Baue[9] reported in 1963 on emergency department thoracotomy. In 1974 Mattox et al.[10–12] reported the first major reviews; 166 patients underwent emergency department thoracotomy as part of a resuscitation effort after major injury, and 45 survived to discharge.

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Subsequently, however, successful emergency department thoracotomy became defined only in terms of a patient's fully intact neurologic status at discharge from the hospital, rather than as a tool of emergency resuscitation of the mortally injured.[13]

The impact that the damage control paradigm has had on survival and other advances in trauma and critical care has caused many to rethink their approach to exsanguinating injury.[14–20] The concept of damage control resuscitation is but one example.[21] As many of these patients arrive at the treatment facility moribund, we have sought to re-examine our experience at the very beginning of the trauma effort by looking at the efficacy of emergency department thoracotomy as a resuscitative tool.

Materials and methods

A retrospective review of the trauma registry from 1993 to 2014 was performed searching all the current procedural terminology (CPT) codes 32000–32500 which identified all patients who underwent thoracotomy at a level I suburban trauma center for any reason at any time during their hospitalization. In addition, the weekly mortality and morbidity conference minutes were reviewed for the same time period. All the charts identified were then individually reviewed to determine whether a thoracotomy was performed in the Trauma Receiving Area of the Emergency Department. A total of 69 cases of emergency department resuscitative thoracotomy (EDRT) were identified. These charts were then reviewed in detail for pre-hospital information, trauma receiving area data and treatment, subsequent course, and outcome. Survival of emergency department resuscitative thoracotomy was defined as restoration of vital signs and transport out of the trauma resuscitation area (TRA) to the operating room, and these patients were designated as "responders". Therapeutic thoracotomies were defined as those which were found to have intrathoracic injuries accounting for the patient's condition and potentially amenable to the intervention in the emergency department. Statistical analysis was performed using Chi-square and Fisher's exact test. Statistical significance was attributed to p-values less than 0.05.

Results

Sixty-nine patients were identified, of which 68 charts were available for review. There were 51 males and 17 females, with a mean age of 35.5 years (range 13–83). Ten patients sustained gunshot wounds, four of whom sustained multiple gunshot wounds, one sustained a shotgun wound, 11 sustained stab wounds; 17 were pedestrians struck by automobiles; 24 were occupants in a motor vehicle crash; four were motorcyclists; and two patients were injured by falling 10 feet. Insufficient emergency medical services run sheets were available to make a meaningful evaluation of pre-hospital times. The mean ISS was 34.3 for the 68 patients overall and ranged from 16 to 75 (Table 1). The time from arrival to EDRT ranged from <1 to 89 min. The indications for EDRT were a witnessed arrested (in the trauma receiving area for 26 patients, in the ambulance for 9 and at the scene for 14), organized cardiac activity upon arrival (33 patients), penetrating trauma in the face of no blood pressure (chest 18 patients, abdomen 3 patients), and child in arrest (10 patients). The indication for EDRT could not be determined in eight cases.

Forty-one patients did not respond to the EDRT and were declared dead in the trauma receiving area (non-responders). Sixteen patients died as a result of exsanguination, nine died from head injuries, 13 from cardiac injuries, five from aortic injuries, four from pulmonary hilar injuries, and two from multiple traumas. Two patients had both exsanguination and head injuries.

Twenty-seven patients (39.7%) were successfully resuscitated in the trauma receiving area (responders), of whom 16 expired in the operating room. Five patients died of unspecified exsanguination, one of whom also had a head injury. Three patients had an aortic disruption, two of whom also had a head injury. Two patients had pulmonary hilar disruptions, two had inferior vena cava injuries, and two had grade V liver injuries. One patient had a cardiac injury, and one patient had a combined iliac artery and vein injury.

Eleven patients survived to the surgical intensive care unit, of whom seven died within 18 h. Two patients succumbed with coagulopathy and five died as a result of head injuries. Four patients survived more than 24 h: one died on the second hospital day due to a closed head injury; one was pronounced brain dead on the fifth post injury day; one expired on post injury day 25 in a persistent vegetative state; and one patient was discharged with a minimal brain injury.

The responder and non-responder groups were similar with regard to male/female ratio, blunt versus penetrating trauma, ISS scores, Glascow coma score, initial blood pressure, pupil reactivity, or time in the trauma receiving area before EDRT (Table 1).

A palpable pulse was present upon arrival in 16 of 27 responders (with a mean pulse rate of 108.3) and in only seven of 24 non-responders (with a mean pulse rate of 76.3). This did not reach statistical significance, with a p-value of 0.06.

Organized cardiac activity was present upon arrival to the trauma receiving area by electrocardiographic monitoring in 23 of 27 responders. The rhythm was tachycardia in 13 patients, normal sinus rhythm in three, and bradycardia or wide complex in seven. One patient arrived in ventricular fibrillation and three arrived in asystole. Among non-responders, organized cardiac activity was present in 19 of 41 patients. The rhythm was tachycardia in one patient, normal sinus in two, and bradycardia or wide complex in 16. Six arrived in ventricular fibrillation, two with pulseless electrical activity, and 14 arrived in asystole. The difference in response to EDRT between those patients who arrived with organized cardiac activity versus those who had arrived without organized cardiac activity was significant ($p = 0.003$). Not surprisingly, the most advantageous rhythm upon arrival was tachycardia ($p = 0.0001$).

The time interval from the last sign of life to EDRT was determined for 67 of the 68 patients by reviewing the emergency department records and pre-hospital run sheets (Table 2). Twenty-nine patients had witnessed arrests in the trauma receiving area, of whom 17 were successfully resuscitated. Six patients had a time interval between 3 and 7 min, of whom two responded to EDRT. Fourteen patients had a time interval between 8 and 14 min, of whom four were responders. Seven patients had a time interval between 15 and 20 min, of whom three were responders. Only one of 11 patients with a time interval greater than 20 min responded to EDRT. While nearly half of the patients who had signs of life reported at the scene responded to EDRT, only three patients who did

Table 1
Demographics of patients.

	Responders	Non-responders	p value
Cases	27	41	
Male/Female	21/6	30/11	NS[a]
Age (range)	28.8 (13–71)	40.3 (5–83)	NS[a]
ISS (range)	33.4 (16–75)	35.1 (19–75)	NS[a]
Signs of life at scene	88.9%	34.1%	NS[b]
Signs of life in ED	81.5%	41.5%	NS[b]
Non-therapeutic EDT	81.5%	53.7%	NS[a]
Blunt/Penetrating injury	21/6	26/15	NS[b]

[a] Chi-square test.
[b] Fisher's exact test.

not have signs of life at the scene responded to EDRT. These three patients did have organized cardiac activity upon arrival to the TRA.

Sixteen of the 47 blunt injured patients had intrathoracic injuries. Twelve patients had hemothorax, four had cardiac rupture, four had avulsion of the pulmonary hilum, two had a ruptured aorta, and two had pericardial tamponade. The intrathoracic findings of the six patients with intrathoracic injury who responded to EDRT were hemothorax in two patients, hemothorax and aortic rupture in one patient, hemothorax and pulmonary hilar avulsion in two patients, and pericardial tamponade in one patient. Of the 31 blunt injured patients without intrathoracic findings, 15 responded to emergency department resuscitative thoracotomy.

Among the 21 patients injured via penetrating mechanisms, 15 were found to have intrathoracic injuries. Ten patients had cardiac injuries, four had pericardial tamponade, seven had hemothorax, and four had pulmonary injuries. Only two responded to EDRT. Two patients had injuries only below the diaphragm and both responded to EDRT. Two patients had injuries to the chest and abdomen, of whom one responded to EDRT. Two patients sustained stab wounds to zone I of the neck extending into the mediastinum, one of whom responded to EDRT.

There were three long term survivors: One blunt injured patient with pericardial tamponade, one blunt injured patient without intrathoracic findings, and one patient with a zone I neck stab wound which extended into the mediastinum. One patient was declared brain dead on the fifth day, one succumbed on the 25th day in a persistent vegetative state, and the third was discharged after two months with mild cognitive deficits. All three long term survivors had witnessed arrests.

Thirty-five patients had signs of life at the scene. Seventeen of 28 blunt injured patients (60.7%) and three of seven patients with penetrating injuries (42.9%) responded to EDRT. All three long term survivors came from this group. Only 7 patients who had no signs of life at the scene responded to EDRT, none of whom survived 24 h (Table 3).

Twenty-six patients arrived in the trauma receiving area without signs of life, of whom four responded. None survived 24 h. The mean estimated time from last sign of life (pre-hospital) to emergency department resuscitative thoracotomy for the four patients who responded was 12.75 min (range 10–15 min), as compared to 20.75 min (range 3–55 min) for the non-responders. Forty-two patients arrived with signs of life, of whom 21 responded (blunt: 18 of 31, 58.1%; penetrating 3 of 11, 27.3%) and were taken to the operating room (Table 3).

Six of 15 patients who presented with organized cardiac activity as the sole sign of life responded to EDRT. The mean estimated time from last other sign of life (i.e. palpable blood pressure or pulse, or fixed and dilated pupils) to EDRT for the four patients who responded was 9.83 min (range 0–25 min), as compared to 8.67 min (range 0–16 min) for non-responders (Table 3).

Ten of 11 pediatric patients (ages 4–17) were injured through blunt mechanisms. Both patients who underwent EDRT solely on the basis of youth had no signs of life upon arrival and were declared dead in the TRA. The remaining nine demonstrated some sign of life in the TRA, seven of whom had arrests witnessed in the TRA or ambulance. Seven responded to EDRT. Two expired in the operating room. The five remaining expired in the surgical intensive care unit at a mean time of 6 h 9 min after admission (range: 2 h 40 min–15 h 32 min).

Twenty-six patients sustained head injuries, all through blunt mechanisms of injury. Thirteen responded to EDRT. Of the 21 blunt injured patients who did not have head injuries, eight patients survived the EDRT. None of the 21 patients injured through penetrating mechanisms sustained head injuries, and six survived the EDRT.

There sole parameter which was predictive of non-response to EDRT was the absence of signs of life at the scene with no organized cardiac activity upon arrival to the TRA.

Table 2
Time interval from last sign of life to EDRT.

	Responders ($n = 27$)	Non-responders ($n = 40$)	p value
<3 min	17	12	0.02[a]
3–7 min	2	4	1.00[b]
8–14 min	4	10	0.37[b]
15–20 min	3	4	1.00[b]
>20 min	1	10	0.04[b]

[a] Chi-square test.
[b] Fisher's exact test.

Table 3
ED thoracotomy efficacy.

	Responders	Non-responders
No signs of life at scene	11.6%	84.0%
Signs of life at scene	85.2%	34.1%
Signs of life in trauma resuscitation area	81.5%	41.5%
Intra-thoracic pathology identified at EDT	22.2%	46.3%
No intra-thoracic pathology (strictly resuscitative)	77.8%	53.7%

Discussion

There is no question that emergency department thoracotomy for resuscitation is a highly morbid intervention which should be used only for patients who are in extremis. However, given the costs of this avenue of intervention and the risks of blood borne infection to the treatment team, some authors have sought to further define the population most likely to benefit. As a consequence, there is an excluded population which is labeled as not warranting resuscitative thoracotomy because as a group they have a poor outcome. In 1979 Moore et al[13] reported 146 patients, of whom only 12 survived to discharge, four with severe brain injury. Specifically excluded from their retrospective report were all patients with suspected cardiac injuries. They concluded that 1) patients with no signs of life at the scene not undergo resuscitation, 2) patients who arrive without signs of life but with a history of signs of life at the scene be selectively resuscitated if they are not victims of multiple trauma or blunt trauma, and 3) patients who do not respond are not transported to the operating room. Despite the bias introduced by excluding suspected heart injured patients and, as subsequently pointed out by Trunkey in the discussion of Harner,[22] that these resuscitative thoracotomies were performed by first- and second-year surgical residents, this publication redefined successful emergency department thoracotomy as a function of patient condition at the time of discharge from the hospital, instead of response to the intervention. Further, the concerns expressed by Lucas in the same discussion, that this study would limit the indications for resuscitative thoracotomy, were borne out as many centers excluded blunt injured patients entirely from resuscitative thoracotomy algorithms.

Victims of blunt trauma who have the poorest prognosis for survival have been demonstrated by a variety of authors, with survival to discharge ranging from 0.0 to 2.9%.[13,22–40] No patients with blunt trauma survived to discharge in the current study. We agree, however, with the concept of "potential survivor" as described by Fulton.[36] We believe that the potential survivor constitutes the patient population for whom the opportunity for survivability should be provided. For the above studies in which survival of the resuscitative thoracotomy can be determined, 0.0–18.7% of blunt injured patients[23,27,31,36,38–40] and 8.7%–78.6% of all patients[13,16,19,20,22–25,27,28,31–33,35–37,41–43] regained a sustained heartbeat. In the current study 11 of 43 blunt injured patients (25.6%) and 27 of all 68 patients (39.7%) regained a sustained heartbeat.

One critical determinant of success for emergency department resuscitative thoracotomy has been the neurologic condition of the patient at the time of discharge from the hospital. This definition does not consider emergency department thoracotomy as a tool of resuscitation and rejects the concept of the potential survivor. The question ought not to be an endpoint of neurologic status at the time of discharge. The real question is how long the brain can tolerate inadequate oxygen delivery. Using a model of circulatory arrest in dogs, Kramer[43] demonstrated that in the normothermic dog, electroencephalographic flat line occurred 20 s after circulatory arrest when brain tissue adenosine triphosphate levels were still greater than 90% of baseline concentration. Brain adenosine triphosphate (ATP) levels would return toward normal after up to 8 min of circulatory arrest. The critical point for recovery of brain ATP levels with the restoration of circulation was 20% of baseline brain ATP concentration; below this level recovery did not occur. Michenfelder[44] studied ATP depletion in the dog brain after decapitation. In this model, the electroencephalogram (EEG) became flat within 15 s. He found a rapid rate of ATP depletion to approximately 25%–30% pre-decapitation levels at approximately 4 min, after which point the rate of ATP depletion slowed, a phenomenon also identified by Kramer. Similar findings have been reported for rats.[45–47] There are reports of ischemia times being tolerated with little or no subsequent neurologic deficits in rabbits up to 20–30 min,[48] dogs up 28 min,[49] and monkeys up to 20–24 min.[50] A cat regained integrative neurologic function and normal EEG and evoked potentials after 1 h of normothermic circulatory arrest.[51]

There is evidence that the human brain is similar.[52–55] There are isolated reports of neurologic recovery in humans after 18 min of normothermic exsanguinating circulatory arrest[56] and 20 min of normothermic cardiac arrest.[57] This 18–20 min time frame appears to be the upper limit of the brain's tolerance to global ischemia.[58] In the clinical situation, it is unclear what impact exsanguinating injury has on this time frame with regard to cerebral autoregulation of blood flow, rate of exsanguinating bleeding, and the observation of loss of signs of life. Brain ischemia from exsanguination may be better tolerated than brain ischemia from cardiac arrest by limiting glucose metabolism and the consequent acidosis associated with anaerobic glucose metabolism.[56] While it is unclear what is the minimum rate of blood flow to maintain brain viability and aerobic metabolism, canine evidence sets this level between 20% and 30% of normal cerebral blood flow.[59]

Some have advocated a more restricted use of EDRT based on the risk of blood-borne infection to the treatment team.[22,30,60] This is not an appropriate reason to withhold the resuscitation effort.

Blood exposure can be minimized by the use of universal barrier precautions. Integrating universal barrier precautions compliance into the emergency department and the trauma program continuous quality improvement and ongoing education programs can maximize compliance by the resuscitation team.[61]

Sikka et al[60] developed a theoretical model for the risk of human immunodeficiency virus (HIV) during EDRT, assuming a prevalence rate for HIV of 7.1% based on data from the 1980's, and assuming a 10% percutaneous injury rate. Their calculated probability for acquiring HIV during an EDRT was 0.00004 (Probability is measured on a scale from Zero = Impossible to One = Certain). More recent reports place the prevalence of HIV below 1%.[62,63]

Percutaneous injuries may be less avoidable during EDRT. The incidence of percutaneous injury to surgeons in the operating room ranges from 1.2% to 3.5%.[64–66] Whether trauma and emergency procedures increase or decrease the risk of percutaneous injury is unclear.[65,66]

When considered in the context of Sikka's model[60] these factors drive the estimated risk even lower, and entirely consistent with findings reported by the Centers for Disease Control.[67]

Of the 58 cases of US healthcare workers with documented occupational acquired HIV infection reported to the Center for Disease Control through December 2013, none were emergency medical technicians, none were surgeons, and two were surgical technicians.[67,68] In fact only one confirmed case has occurred since 1999, a research laboratory technician. These figures are even more significant since surgeons are considered to be among the highest occupational risk.

Some have advocated a more restricted use of EDRT based on the cost of the resuscitation effort, not only in the emergency department, but also the operating room, intensive care unit, and rehabilitation or nursing home facilities, especially for survivors who are severely brain injured.[30,34,39,69] Baker estimated the benefit to cost ratio for emergency thoracotomy to be 2.4/1[24], and Branney estimated the benefit to range from 1.8 to 5.6 to 1.[23] Clearly, the impact of the procedure to society in terms of the monetary contribution of the survivors, including subsequent miscreant employment or recidivism, cannot be accurately determined.

Conclusion

We believe that the potential survivor is the individual for whom Beall, Baue, and others originally conceived the concept of emergency department resuscitative thoracotomy in the 1960s, the individual for whom the opportunity of survival should be provided. Emergency department resuscitative thoracotomy remains the last best chance for survival in the acutely dying trauma patient. Success of this intervention is most appropriately defined as restoration of adequate vital signs to allow transport of the patient to the operating room, where advances in volume restoration, intra-operative resuscitation, and operative techniques may result in transfer of the patient to the intensive care unit, rather than the morgue. In the intensive care unit, that patient will have the opportunity to benefit from further advances in critical care therapies in much the same way as damage control patients have benefited. Given the improvements in pre-hospital response and care, the parameters by which emergency department resuscitative thoracotomy is initiated should therefore be reassessed. We believe that the sole criterion by which the EDRT should be evaluated is as a tool to aid the resuscitation of the mortally injured. This is the success of the intervention itself to achieve its goals, not the ultimate outcome of the patient. Resuscitative thoracotomy is warranted for any patient with thoracic or subdiaphragmatic trauma who presents in extremis with a history of signs of life at the scene or organized cardiac activity upon arrival. Patients who have no evidence of signs of life at the scene and have no organized cardiac activity upon arrival should be pronounced.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. As this was a retrospective study of a standard therapy, IRB approval was not required.

Informed consent

The intervention of this retrospective study was emergent treatment of conditions which were immediately life threatening. Informed consent could not be obtained under these circumstances. The intervention in this retrospective review is standard therapy under those conditions.

Availability of data and materials

The raw data for this retrospective review was obtained directly from patients files. Those files will not be made available for review in accordance with the United State Health Information Patient Portability Act. The de-identified and aggregate data can be made available for review from the corresponding author, Dr. DiGiacomo, if requested.

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