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Emergency Department Thoracotomy as an Intervention for Penetrating Trauma to the Thoracic Cavity: A Systematic Review

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ABSTRACT

Emergent thoracic surgery involving the heart has been taking place for 126 years. Thoracic penetrating trauma is occurring more and more frequently in the US, and while 90% of patients with penetrating thoracic trauma die en route to hospital, the ones who arrive in extremis have better chances of survival now than ever due to an improving 60+ year practice of emergency department thoracotomy (EDT). This review has a primary objective of comparing the literature and history of EDT as a lifesaving intervention for patients with penetrating thoracic trauma and resulting mortality. It also aims to give context on EDT as an emergent intervention with respect to the pathophysiology occurring in patients requiring this intervention and how EDT fits in with the rest of the treatment received by trauma patients with severe intrathoracic injuries.

This is a systematic review utilizing keywords: “thoracotomy,” “EDT,” “resuscitation,” “penetrating,” “gsw,” “stab,” “emergency,” “thoracic,” and “injury” to search the databases of PubMed, Google Scholar, and Science Direct.

While EDT remains a procedure with low survival to discharge (5-25%), there are cases which are most favorable to the procedure, namely patients who arrive with SOL, have a single penetrating wound to the heart that is not inflicted by a bullet.

EDT is a tried-and-true method for patients who will not otherwise survive. However; only recently have large meta-analyses been put together because this is a very high risk, and an infrequently performed procedure. There is also call for conservative management and temporizing measures such as REBOA, though there is still no ICD code, and too little research to consider this controversial procedure comparable to EDT.

INTRO

There are those extraordinary cases in trauma where someone is pulled back from the brink of death and seemingly insurmountable odds and through the efforts of a medical team survive. Emergency department thoracotomy (EDT) is a means of doing just this by making a surgical incision between the ribs to gain access in the thoracic cavity to a damaged heart, lungs, or greater blood vessels, control bleeding and save a life. In the US, "Thoracic injuries represent one of the leading causes of death in all age groups, and account for 25–50 % of all traumatic injuries,"[1] and are "responsible for approximately half of all traumatic deaths,"[1] additionally, "10–15 % of patients with penetrating thoracic injuries require an immediate thoracotomy as part of their initial resuscitation."[1] The American trauma system has standardized how emergent care is provided in life-threatening cases involving penetrating injuries to the thoracic cavity (most often gunshot wounds (GSW) and stab wounds (SW) and as a result there is a growing body of literature describing thoracotomy as emergent lifesaving management of penetrating trauma to the thoracic cavity with extreme hypovolemia due to blood loss and cardiac or greater vessel injury (CGV) for patients in extremis. Unfortunately, "Gunshot wounds remain the most common cause of penetrating injuries in children and adolescents and the second leading cause of death among youth in the United States."[2] This makes EDT a more important procedure now than ever.

METHODS

This review aims to give a comprehensive overview of the current literature, identify the benefits to using EDT as an emergent intervention to treat penetrating trauma and its associated mortality, and describe its history and efficacy in clinical practice. The study will be conducted using a systematic review to collect and analyze data from relevant studies. The review will involve the following steps:

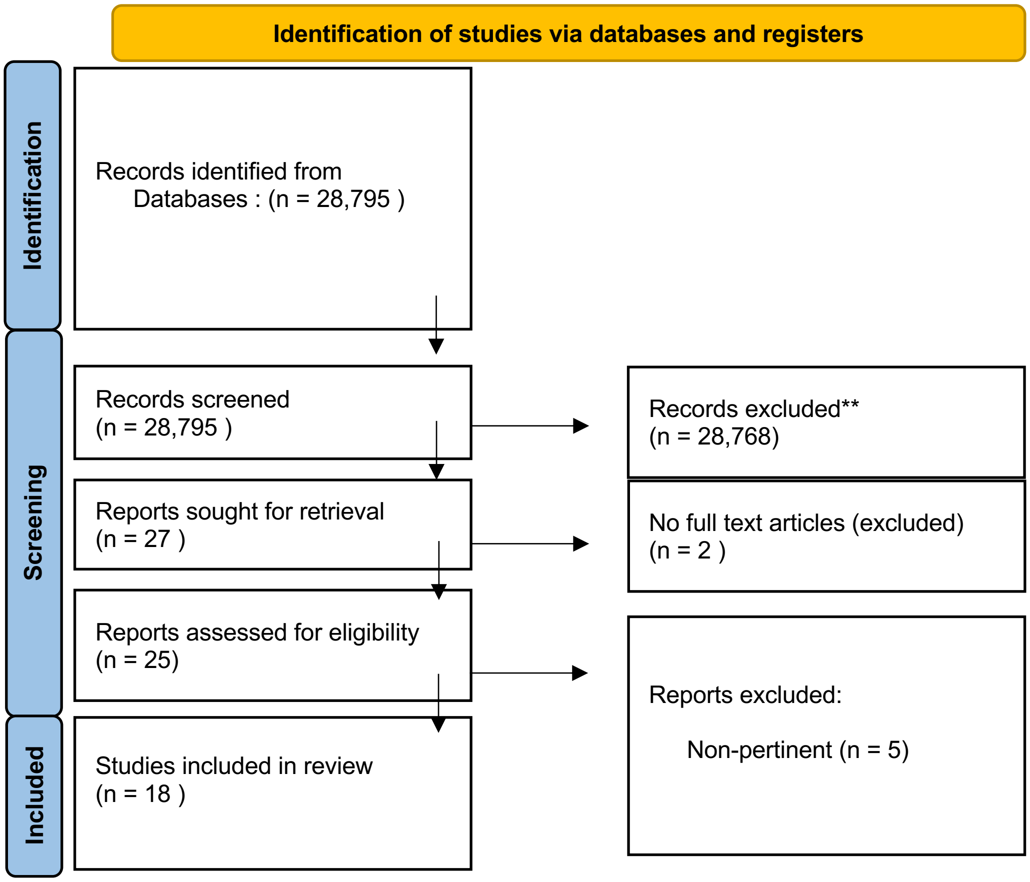
1.) Eligibility criteria: the search results will be screened based on inclusion and exclusion criteria. The inclusion criteria include studies that discuss emergent thoracotomy for penetrating thoracic trauma. The exclusion criteria exclude studies that do not focus on emergent thoracotomy or thoracic penetrating trauma, or do not answer the research question and studies whose full text could not be found.

2.) Search strategy: a comprehensive search of online databases including PubMed, Google Scholar, and ScienceDirect will be conducted to identify studies published from 2018 to 2023. Searches will use the keywords “thoracotomy + resuscitation”, “gsw + thoracotomy”, “thoracotomy + penetrating”, “thoracotomy + stab”, “thoracic + injury”, “emergency + thoracotomy.” Initially this excluded many important studies. Since I wanted a historical and emerging overview including crucial metanalyses that often took place over more than a decade, I decided to expand my search to include studies older than 5 years.

3.) Data collection process and analysis: selected studies will undergo a comprehensive review, with data pertaining to the population, intervention, control, and outcomes extracted and analyzed. The data analysis will be conducted using a qualitative approach, and the findings from the selected studies will be synthesized and compared.

4.) Interpretation of results: Findings will be interpreted to determine best cases for patient survival after EDT for penetrating thoracic trauma, synthesized to better understand the broader implications for research conducted on this procedure, to discuss its history, and explain its role in management of this patient population, and to describe accompanying pathophysiology of penetrating thoracic trauma.

It is necessary to acknowledge the possibility of bias in this paper. There were many articles which were inaccessible to me due to the lack of access to paid articles of many prominent surgical societies, so I relied on free materials through Augsburg University's Library. I would like to acknowledge the assistance of Mark J. Seamon, MD, FACS, a prominent trauma surgeon who was kind enough to share one of his papers with me. His research has been instrumental to the practice of trauma surgery and to the understanding of EDT.



The above figure shows the selection process for literature in this review. Of the 28,785 articles found through database queries, (PubMed: 297, Science Direct: 288, Google Scholar: 28,200) 28,768 were excluded based on their relevance to the stated search. Only 25 of the 27 remaining articles were retrieved because 2 did not have full text, and a further 5 were excluded because they didn't really answer the research question despite relevance to the topic. The remaining 18 articles were used in this research study and may be seen in the references.

RESULTS

Definition

Emergency department thoracotomy (EDT) is performed in the emergency department or trauma bay as opposed to emergency thoracotomy (ET/ORT – which is performed in the OR) on patients with intrathoracic injuries who are hemodynamically unstable or experiencing cardiac arrest and not responding to fluid resuscitation measures to gain access to vital structures in the thoracic cavity. The most commonly used method in the US is the left anterolateral thoracotomy. A 10 blade scalpel is used to incise the skin, subcutaneous fat, and chest wall musculature at the fifth intercostal space starting at the sternum (this saves time if sternal transection is required later,) and cutting transversely, curving upward to the axilla following the natural curve of the ribs.[3] The intercostal muscles and parietal pleura are separated using a curved mayo scissors or scalpel taking care to cut following the top of the fifth rib to avoid damaging the neurovascular bundle of the rib above. A Finochietto's rib retractor is used to spread the ribs apart with the handle facing the bed rather than the sternum allowing for extension into a clamshell thoracotomy across the sternum without moving the retractor. This allows rapid access to the heart and greater vessels such as the aorta.

If a left anterolateral thoracotomy doesn't give enough exposure, it may be extended through the sternum and across the right chest using a Lebsche's knife and mallet, but the internal mammary vessels must be ligated to prevent bleeding. This bilateral thoracotomy is often referred to as a clamshell or butterfly thoracotomy and provides better access to the right side of the thoracic cavity, both pleural cavities, and anterior and posterior mediastinum. Though it is a brutal and daunting procedure, "London's Air Ambulance which is staffed by non- trauma surgeons published data on 71 prehospital thoracotomies using a clamshell technique and reported the survival of 13 patients,"[4] showing that even in the hands of generalist, non-trauma personnel the clamshell variant of EDT can, "provide a significant probability of survival."[4] In other cases requiring even further access, the superior sternum is split higher up the midline to visualize the aortic arch and other superior vascular structures (sternotomy).

EDT may be performed to create a pericardial window and release cardiac tamponade and pericardial clots; control cardiac and greater vessel (CGV) hemorrhage; manage intrathoracic hemorrhage; needle decompress massive air embolism; perform cardiac massage; cross clamp the aorta and/or greater vessels; and perform hilar twist to control pulmonary hemorrhage and prevent air embolism. These are the primary objectives of EDT, but there are certainly other conditions which may be aided by the access provided by EDT such as thoracoabdominal or multisystem injuries.[3]

History

Thoracotomy was first used in a resuscitative capacity in the late 1800's to perform cardiac massage on patients undergoing surgery who arrested due to iatrogenic injury usually involving anesthesia. Below follows an account of the first successfully recorded cardiac repair:

In 1897, Ludwig Rehn Published a full account of cardiorrhaphy (cardiac repair by suture) performed on September 9, 1896. A 22-year-old man had been stabbed in the left fourth intercostal space; he developed a rapidly increasing hemothorax and appeared near death. Rehn recounted, "There remains one question: what is injured, the heart or its great vessels, an intercostal artery, or the internal mammary . . . ? The tract of the wound lay in the direction of the heart. I decided to attempt to arrest the bleeding."[5]

Rehn encountered a [1.5] cm wound of the right ventricle, pouring forth blood. Controlling the bleeding with digital pressure, Rehn closed the wound with three sutures of silk,

"It was very disquieting to see the heart pause in diastole with each pass of the needle.. . The heart gave a labored beat, and then resumed with forceful contractions as we breathed a sigh of relief."[5]

With the invention of CPR and external chest compressions in 1960 and the first uses of external defibrillation in 1965, thoracotomy was no longer performed for medical cardiac arrest. However, advances in cardiothoracic surgery in the 60s led to the use of thoracotomy as a viable means for treating patients with intrathoracic injuries. The development of aortic occlusion for patients exsanguinating, and of creating a pericardial window in the case of cardiac tamponade increased its usage in trauma cases.

With the proliferation of semi-automatic firearms and higher rates of penetrating injuries, and with advances in prehospital care and decreased transport times due to the implementation of regional trauma systems since the 1980s, more patients make it to EDs alive, albeit in extremis. As a result, EDT has seen extensive usage in EDs in the US and around the world. In 2013 "952 emergency thoracotomies were performed in the US on the day of presentation to a hospital."[6]

"Over the past two decades, there has been a trend towards larger caliber more destructive weapons, and an increase in semi-automatic weapons,"[7] and a retrospective analysis out of Denver Health Medical Center states, "victims of gunshot wounds are presenting with higher ISS [injury severity] scores and an increase in the number of severe gunshot wounds. Additionally, mortality from firearms increased…, whereas mortality from every other injury mechanism remained the same or improved."[7] Even as we become more effective at treating penetrating trauma, the weapons killing Americans are becoming more deadly. Efforts to identify predictors for mortality and codify best use cases for EDT have aimed to resolve the contentious issue of when to perform EDT given the extreme cases of injury they are performed in and the relatively high rates of mortality (5-25%)[7] depending on factors such as mechanism of injury (MOI), signs of life (SOL – pupillary response, spontaneous ventilation, presence of carotid pulse, measurable or palpable blood pressure, extremity movement, or cardiac electrical activity),[8] and vital signs (electrical activity, respiratory effort, or pupillary response despite lack of palpable BP). While EDT is still indicated in some cases of blunt force thoracic trauma, I have chosen to focus on its use in penetrating trauma due to the very low survival rate in blunt injury patients (4.7% with SOL and only .7% without SOL.)[9]

Pathophysiology of penetrating thoracic injuries

To understand the importance of EDT in treating intrathoracic injuries it's essential to recognize the life-threatening pathologies that arise from GSW and SW. When someone is shot or stabbed they are at risk of bleeding out, and although many EMS rigs have paramedics that can give IV saline to replace fluids, life-threatening bleeds must be stopped, or the patient will exsanguinate. As blood is lost the body loses its ability to perfuse the organs with the oxygen they need. In order to continue functioning, cells begin anaerobic respiration, breaking down glucose and creating lactic acid. As the blood becomes more acidotic from the lactic acid two things occur; clotting proteins that aid clotting stop functioning well without the specific pH range they prefer, and hemoglobin in red blood cells (RBCs) binds oxygen less effectively due to the Bohr effect. As the body starves for oxygen it goes into compensated shock. Peripheral blood vessels contract forcing what blood is left back to vital organs, heart rate and breathing increase, and the body drops in temperature as blood distributes heat less effectively. This state of hypothermia further compounds the difficulty in protein factors being able to clot effectively. This cycle of acidosis, hypothermia, and coagulopathy are known as the trauma triad or the lethal triad. Patients will look cool, gray and clammy as this progresses. Severe hemorrhagic injuries are lethal unless treated accounting for the statistic that, "about 90% of patients with penetrating thoracic injuries die before reaching the hospital."[2]

Cardiac tamponade

Exsanguination is not the only fatal condition caused by penetrating thoracic injuries, nor is it the only indication for EDT. When the heart or one of its many vessels has been damaged, the resulting bleeding into the pericardial sac begins to exert pressure against the heart often causing right ventricular (RV) collapse when filling, decreased cardiac output, and eventually cardiac arrest. This can manifest in clinical signs known as Beck's triad; low blood pressure, distended jugular veins (as blood pressure is backed up from the RV to the IVC all the way up the jugular), and diminished heart sounds on auscultation. Cardiac tamponade may also be observed in point of care ultrasound (POCUS) with these key findings, " a pericardial effusion, diastolic right ventricular collapse (high specificity), systolic right atrial collapse (earliest sign), a plethoric inferior vena cava with minimal respiratory variation (high sensitivity), and exaggerated respiratory cycle changes in mitral and tricuspid valve in-flow velocities as a surrogate for pulsus paradoxus."[10] While these all sound like very bad things and allowing them to progress to the point of cardiac arrest certainly is, "Cardiac tamponade can be advantageous by allowing time for definitive measures,"[2] in that by creating tamponade, the pericardium is preventing massive bleeding into the thoracic cavity, and "within the group of people who do survive, cardiac tamponade physiology is usually found."[2] However, "filling of the pericardium… limits the stroke volume so in response cardiac frequency and right heart filling pressures are elevated through catecholamine production until [the] right heart's distensibility limit is reached, septum is pushed to the left side, and [the] left side's function is finally compromised. For this reason, the longer the decompression of the pericardial space is delayed, a poorer prognosis should be expected."[11] There is a very narrow window for which tamponade is protective before it becomes lethal which is why EDT is such an essential technique in this patient population.

HTX, PTX and Hemopneumothorax

Patients with a penetrating wound to the chest may also experience pneumothorax (PTX) as air leaks into the pleural space and overwhelms the negative pressure needed for inspiration collapsing the lung, or hemothorax (HTX) where that same space and even the lung itself fills with blood, or a combination of the two; hemopneumothorax. Paramedics can temporarily resolve a pneumothorax with needle decompression, but definitive treatment for more significant PTX and for HTX is chest tube, and when that is not enough due to significant bleeding, EDT is necessary as "the risk for death increases linearly with total chest hemorrhage after thoracic injury. Thoracotomy is indicated when total chest tube output exceeds 1500 mL within 24 hours, regardless of injury mechanism."[12]

Victims of penetrating thoracic trauma may suffer any combination of these pathologies in addition to other injury patterns in the abdomen, head, neck or extremities. On arrival to the ED hypotensive trauma patients will undergo a primary trauma survey focused on circulation, airway and breathing (CAB) and appropriate interventions such as massive transfusion protocol (MTP), chest tube insertion, and if indicated EDT.

INDICATIONS FOR EDT

There are many guidelines and algorithms describing indications for EDT including those from the Western Trauma Association (WTA), Eastern Association for the Surgery of Trauma (EAST) and the DOD's Joint Trauma System (JTS). The EAST guidelines came from an analysis of 72 relevant studies to assess when EDT should be employed, and in which cases ending resuscitation should be considered, and are more or less in agreement with the larger body of literature. As stated by EAST:

> We strongly recommend that patients who present **pulseless with signs of life after penetrating thoracic injury** undergo EDT. We conditionally recommend EDT for patients who present **pulseless and have absent signs of life after penetrating thoracic injury**, **present or absent signs of life after penetrating extrathoracic injury**, or **present signs of life after blunt injury**. Lastly, we conditionally **recommend against EDT for pulseless patients without signs of life after blunt injury.**[9]

Regarding how the EAST guidelines were determined based on the referenced meta-study, "The 72 included studies provided 10,238 pulseless patients who underwent EDT. Patients presenting **pulseless after penetrating thoracic injury had the most favorable EDT outcomes** both **with [SOL]** (**survival, 182 [21.3%**] of 853; neurologically intact survival, 53 [11.7%] of 454) and **without [SOL]** (**survival, 76 [8.3%**] of 920; neurologically intact survival, 25 [3.9%] of 641) **signs of life**." Regarding blunt trauma, "outcomes after EDT in pulseless blunt injury patients were limited with signs of life (survival, 21 [4.6%] of 454; neurologically intact survival, 7 [2.4%] of 298) and dismal without signs of life (survival, 7 [0.7%] of 995; neurologically intact survival, 1 [0.1%] of 825)."[9]

Stated in more functional physiologic terms by a case study from 2020:

Indications for resuscitative thoracotomy include thoracic trauma (blunt or penetrating) with hemodynamic instability that does not respond to fluid resuscitation and shock that is correctable by specific surgical maneuvers such as cross clamping the aorta, pericardial fenestration, direct cardiovascular repair, and evacuation of air embolism.[13]

While SOL on arrival is today the most predictive of survivability for penetrating thoracic trauma, there were earlier studies looking into MOI and location of injury, that while not given as much weight today remain relevant. One study conducted at Temple University comprising 283 cases of cardiac and greater vessel (CGV) injuries across two level I trauma centers in Pennsylvania found that "When the cumulative impact of penetrating injury mechanism, ED SOL, and number of CGV wounds was analyzed together, … those sustaining multiple CGV GSWs (regardless of ED SOL) were nearly unsalvageable… When multiple CGV

GSWs are encountered after EDT, further resuscitative efforts may be terminated without limiting the opportunity for survival."[14] In this study:

Patients were compared by **injury mechanism** and **number of CGV wounds** with respect to **survival (SW, 24.2%; GSW, 2.8%**; *p* □ 0.001; **single**, **9.5%; multiple, 1.4%**; *p* □ 0.003)... Although 6 of the 117 (**5.1%) patients with single CGV GSW survived**, **only one patient** (1 of the 133, **0.8%**, *p* □ 0.053) **with multiple CGV GSW (regardless of ED SOL) survived their hospitalization after EDT. This patient arrived to the [ED] with vital signs, sinus rhythm, and a GCS score of 14 but rapidly decompensated to cardiopulmonary arrest. The patient was successfully resuscitated with an EDT to allow repair of RV and IVC GSW.**[14]

Of note, this patient who survived to discharge with no neuro deficits, by recommendation of the guidelines established in this paper by Seamon et. al, would not have warranted resuscitation after EDT, although by current EAST guidelines (written by many of the same authors) would.

This paper was able to find two parameters that "independently influence survival in multivariate analysis—**injury by gunshot** (OR, 0.09; 95% CI, 0.02–0.38; *p* □ 0.001) and **GCS** (OR, 1.38; 95% CI, 1.19–1.61; *p* □ 0.001)."[14] The authors note, "Patients who sustained CGV GSW were 11 times more likely to die after EDT as those who suffered CGV SW."[14] Wounds caused by knives not only deliver less force, but create a narrow, easily collapsible wound channel while the larger, more irregularly shaped permanent wound cavity created by a bullet both delivers more force and is more lethal. The algorithm proposed in the paper is shown below:

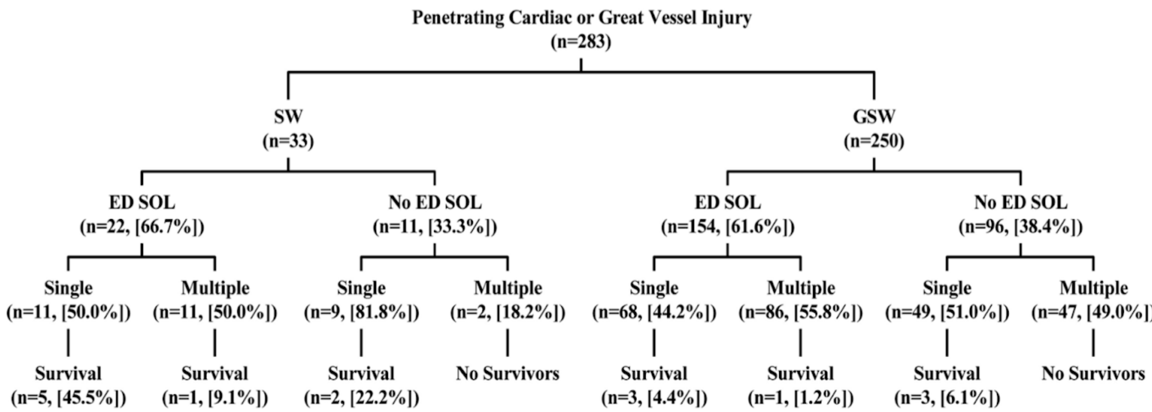


Figure 1. Hospital survival was analyzed with respect to penetrating injury mechanism (stab wounds [SW] vs. gunshot wounds [GSW]), the presence or absence of emergency department signs of life (ED SOL), and number of penetrating cardiac or great vessel wounds (single vs. multiple).[14]

Contraindications

WTA notes that **EDT "is considered futile if** prehospital cardiopulmonary resuscitation (CPR) exceeds 10 minutes after a blunt injury without a response, or if **prehospital CPR exceeds 15 minutes after a penetrating trauma without a response**. In addition, **futility is likely when asystole is associated with no pericardial tamponade**."[15] Additionally, a study from 2020 conducted at University of Arizona asserts that "Initial utilization of the focused assessment with sonography for trauma (FAST) may potentially avoid this futile intervention as the **absence of cardiac motion or pericardial effusion on a FAST examination results in a zero survival rate**."[15]

EDT is also considered futile in many geriatric populations because their physiologic reserve is not great enough to deal with the extreme stress, specifically " in patients with age ≥70 years, regardless of the MOI as well as in those with age ≥60 years with a blunt MOI."[15] They also agree with both WRT and EAST that in terms of MOI “a penetrating MOI is the strongest predictor of survival after an ERT [EDT], with penetrating SWs resulting in the greatest survival rate,”[15] and point out that survival is overall improving for EDT “from 7.9% in 2010 to 11.3% in 2014.”[15] This rate is lower than overall survival for EDT in thoracic trauma because it includes EDT for blunt trauma which approaches zero in some cases.

EDT in modern trauma practices such as Damage Control Resuscitation (DCR)

EDT is rarely a definitive treatment as the injuries which indicate EDT are often grave and complicated requiring further intervention, transfer to other units like the OR and ICU, and multiple or repeat surgeries. DCR is the framework used to employ EDT to access and manage critical injuries, get the patient to the ICU alive, and then re-attempt surgery when the patient is more stable. Thoracotomy is actually best performed in an OR (ET or ORT) with one study showing a 65% survival rate for ORT vs 3% for EDT.[14] Seamon et. al note “clearly, injury and physiologic derangement was more severe in the EDT group as evident by detectable blood pressure (EDT, 22%; ORT, 81%), ISS [injury severity score] (EDT, 52.7; ORT, 28.7), and time to thoracotomy (EDT, 6.1 minute; ORT, 25.0 minutes).”[14] It should be noted that ORT isn’t a wildly different procedure, somehow spiking the survival rate by 62%, but that the patients requiring EDT are usually dying and cannot wait to get to the OR. In many cases definitive surgery is not immediately possible as patients are too critically ill and require massive transfusion protocol (MTP), and critical care in the ICU.

The technique of damage control resuscitation is often achieved through the access offered by EDT. Its history is rooted in “damage control … a Navy term defined as “the capacity of a ship to absorb damage and maintain mission integrity.” When applied to surgery and critically ill patients, [it] incorporates fundamental tenets: arresting surgical hemorrhage, containing gastrointestinal spillage, inserting surgical sponges and applying a temporary abdominal [or thoracic] closure. This sequence is followed by immediate transfer to the intensive care unit (ICU) with subsequent rewarming, correction of coagulopathy and hemodynamic stabilization. Return to the operating theater is then pursued 6–48 hours later for a planned re-exploration that includes definitive repair and primary fascial closure if possible."[16]

Returning to the lethal triad, many patients would experience end organ damage or bleed out if definitive surgery were immediately attempted following EDT. In one case study, DCR and delayed definitive surgery was required due to coagulopathy caused by acidosis with authors noting "An international normalized ratio (INR) of >1.6 has been found to increase the odds of mortality," and that "Acidosis with a pH of <7.0 in the setting of trauma has been shown to increase the mortality rate threefold."[17]

Often due to the nature of multiple GSWs causing extrathoracic injuries in patients with penetrating thoracic injuries or CGVs, in addition to EDT, DCR is a requirement to survival and will be performed concurrently. Interestingly "patients with cardiac injuries enjoyed the best survival after EDT (19.4%), followed by thoracic (10.7%) and abdominal injuries (4.5%),"[14] while those with multisystem traumas fare even worse, often necessitating DCR. Many maneuvers specific to DCR are performed after EDT to speed up and aid in future delayed thoracic surgeries such as "pulmonary tractotomy, stapling of cardiac wounds, and ligating or temporarily bypassing a main vessel."[18] In addition to what EAST has written about the importance of SOL and MOI, "Early clinical signs that can predict whether a patient might meet these criteria in an emergency setting include a heart rate of >120 beats per minute, systolic blood pressure <90 mmHg, positive focused assessment with sonography in trauma scan, and penetrating trauma. If one of the three massive hemorrhage criteria are met with the additional predictors indicated in the emergency setting, then DCR measures are indicated."[17]

CASES

After combing through the literature, two case studies stood out : Two 19 y.o. boys, one lived who by all accounts should have died and according to the algorithm at the time perhaps not been resuscitated, and another who died but was resuscitated and worked up given current algorithms.[2,17] Reading through both abridged accounts will offer a real clinical picture of EDT in practice and help with the discussion following. They are found in the appendices (p.25) if you would like to read through them.

DISCUSSION

These two cases perfectly illustrate one of the most difficult ethical quandaries in emergency medicine. Who gets to live and who gets to die? Ultimately, it isn't up to us to decide, but in emergency medicine by laying out guidelines determining which cases merit a workup, and which cases to call (stop working), we are certainly tipping the scales. In the first case one young man presented with a GSW to the RV and another to the IVC. Describing this exact injury presentation, in the author's own words, "when multiple CGV GSWs are encountered after EDT, further resuscitative efforts may be terminated without limiting the opportunity for survival."[14] This patient went on to live and was successfully discharged from the hospital without neurological deficits even though by the very algorithm proposed by the author at the end of this study he and his team would have been off the hook, and even advised to cease resuscitation. It's important to add that 6 years later one of the same authors of the EAST guidelines wrote, "We strongly recommend that patients who present pulseless with signs of life after penetrating thoracic injury undergo EDT,"[9] and maintaining that view three years later in 2018 writing, "signs of life on arrival to the trauma bay is by far the most important predictor of survival in patients undergoing EDT for both penetrating and blunt trauma,"[7] perhaps explaining the clinical choice to save the life of the young man with multiple CGVs though the guidelines might not have suggested it the decade before. Nothing is absolute, and as our experiences inform us, we become the better for it.

In the other case, another less fortunate young man was shot 31 times in the chest, abdomen, and extremities. This was an unsurviveable collection of injuries, however; " it would have been unethical to discontinue efforts due to the patient's intact neurological exam and initial ability to respond to questions."[17] He was worked up given the guidelines, was able to speak to the team and survived his EDT and DCR and it wasn't until more than 12 hours later that he succumbed to his injuries. My point is, we come up with best practices and guidelines based on the available data, but there will always be outliers. We need to be careful when speaking and thinking in data points because after the fact, on discharge or postmortem these are the lives of real people. There will be cases that we pursue fervently, perhaps even against one of many conflicting guidelines and when we use our best clinical judgment and they survive, were we wrong? How about when they die? There were several cases I read about in the literature where patients were stable, but still bleeding and there was no more blood to transfuse. They bled out and died. We have limited resources and impossible choices to make, and we keep making them. It's a difficult job to do, but if my math is correct even on the most conservative side, every year in the US, hundreds of lives are saved by the practice of emergency department thoracotomy and the teams that perform them.

Limitations

Initially when I sat down to write this my working title was: Treatment Modalities for Penetrating Trauma from Gsw in Minneapolis vs Other High Gun Violence Areas: Chicago and Baltimore. Unfortunately, there's just not enough written about EDT performed in specific locations to make this possible, rather large registers of patients spanning larger, state or national systems are created to combat the otherwise very small sample size, so I pivoted. While this review aimed to capture the width and breadth of the literature, EDT is a complicated, infrequently performed procedure making large, recent meta-analyses few and far between with much of the literature spanning the last twenty to thirty years rather than the last five and even most of the recently published findings all reference materials spanning decades back because the mechanical process of EDT is largely unchanged despite concurrent interventions evolving in practice. I decided that focusing on EDT and its history, as well as including some articles older than 5 years was not only appropriate, but necessary. I also read articles showing nearly identical practices for EDT in the US from France, Israel, Brazil, South Africa, and the Netherlands. I wanted to include what I found in those papers, but I didn't have the time or the pages, and they didn't all answer the research question. Suffice it to say that South Africa favors selective conservatism, Brazil practiced exploratory sternotomy due to an initial shortage of POCUS to diagnose pericardial effusion/tamponade, and Israel showed much better survivability of EDT for blunt trauma due to rapid EMS transport/military integration. The Netherlands was also able to claim equal success in EDT to large volume US centers despite their low volume.

CONCLUSION

Based on all the available literature the patients who enjoy the best survival from EDT present with SOL and penetrating thoracic injuries. Those injured with a knife fare better than those with a gun. Those sustaining a single wound do better than with multiple wounds, and those who have an injury to the heart fare better than those with thoracic or greater vessel injuries. This is not to say that the best chances for survival of penetrating thoracic injury are being stabbed in the heart, rather that in those patients for whom EDT was required (patients in critical condition) that being stabbed in the heart was preferrable to being stabbed in a greater vessel. Obviously, if you must pick a thoracic penetrating injury, missing the heart and greater vessels would be best, but in that case, EDT is likely not required and conservative management for likely PTX with needle decompression or chest tube should suffice.

Speaking of which, selective conservatism is a hot trend and while there is not sufficient data on resuscitative endovascular balloon occlusion of the aorta (REBOA) it is being employed as a temporizing measure to gain hemorrhagic control, more studies on this method may one day place it among commonly accepted adjuncts such as temporary intravascular shunts (TIVS). While I feel confident that this paper gives a decent account of EDT on the national level, I would like to see more localized studies comparing penetrating trauma in major cities afflicted with high volume of gsw. As more research is done in this field, I hope that we can learn from each other and improve survival outcomes for patients with penetrating thoracic injuries.

APPENDICES

CASE I

19-year-old boy who presented to the ED as a trauma code after sustaining a gunshot wound to the right chest.[2] [EDT was performed,] pericardial sac was then incised, and a large hematoma was noted and evacuated, releasing a cardiac tamponade. Return of circulation was noted with a palpable femoral pulse.

In the operating room, a right anterolateral thoracotomy was performed due to persistent chest tube drainage. Once sufficient filling of the heart was achieved, two penetrating wounds on the anterolateral surface of the right ventricle were noted along with pulsatile extravasation. The defects were successfully repaired with 4’0 prolene pledgeted sutures while avoiding the major coronary arteries. The heart was then carefully inspected, and no bullets were identified. Furthermore, penetrating injuries were noted at the middle and lower lobes of the right lung, which were treated with wedge resections.

The patient was profoundly acidotic and coagulopathic and as a result, received a total of 18 units (U) of packed red blood cells, 18 units of frozen fresh plasma, and four packs of platelets during the surgery.

Due to persistent shock and profound coagulopathy, his open chest was covered with a closed-system dressing and the patient was transferred to the surgical intensive care unit for continued resuscitation and supportive management.

On post-trauma day 2, the patient underwent chest closure with the removal of surgical packing. During the surgery, the bullet was palpated within the epicardium along the right ventricular outflow tract. In collaboration with the cardiac surgeon consultant, a decision was made to leave the bullet in place since any attempt at removal would have required the patient to be placed on cardiopulmonary bypass, thereby increasing the stress on the patient.

The patient was discharged on hospital day 30 in stable condition with scheduled outpatient follow-up with the trauma and cardiac surgery teams.

The patient was seen within two weeks of discharge by the trauma and cardiac surgery teams for routine follow-up. He was noted to be progressing without issues and his wounds were all healed.

CASE II

A 19-year-old male experienced postoperative pericardial tamponade after a bilateral resuscitative thoracotomy with pericardiotomy. [17] This patient presented to the hospital in critical condition with 31 gunshot wounds (GSWs) distributed over the chest, abdomen, and extremities. After undergoing an initially successful resuscitative thoracotomy, the patient continued to bleed into his chest at a greater rate than the chest tubes were able to adequately evacuate. Despite the presence of a large pericardial window, clotted blood led to cardiac tamponade. Subsequent bedside reopening of thoracotomy under conscious sedation (ketamine, fentanyl, and midazolam) was required to evacuate the clots and stabilize the patient.

Additional chest tubes and pericardial drains were placed. Over the next 12 hours, the patient was relatively stable, requiring ventilatory support and occasional transfusion. However, the patient suffered cardiac arrest and rapidly decompensated. The patient's chest and abdomen were reopened, showing clotted hemothorax, hemopericardium, and ischemic bowel. The patient suffered a severe anoxic brain injury (GCS 3) and ultimately succumbed to his injuries despite aggressive resuscitation.

Our patient required over 40 units of pRBC, 35 of FFP, and 35 platelets reduced the supply available for other patients. In addition to the non-surgical teams such as anesthesia, pharmacy, nursing, and blood bank, this patient required five hours in the OR for initial damage control with three attending surgeons, two residents, and a physician assistant (PA)**,** followed by two bedside reopenings of the thoracotomy and nearly 24 hours of direct physician attendance in the ICU. This is a significant investment of resources for a hospital of any size. The just and equitable resource distribution was discussed during the care of this patient. However, based on our patient's initial response to intervention, we decided to continue heroic efforts. Despite unprecedented efforts, the patient ultimately succumbed to his injuries. Ultimately, it would have been unethical to discontinue efforts due to the patient's intact neurological exam and initial ability to respond to questions.

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