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Establishing Benchmarks for Resuscitation of Traumatic Circulatory Arrest: Success-to-Rescue and Survival among 1,708 Patients

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Abstract

Background—Trauma patients who present to the hospital in extremis are attempted to be salvaged with emergency department thoracotomy (EDT). EDT allows for relief of cardiac tamponade, internal cardiac massage, and proximal hemorrhage control. Minimally invasive techniques, such as endovascular hemorrhage control (EHC) are available, but their non-inferiority to EDT remains unproven. Before adopting EHC, it is important to evaluate the current outcomes of EDT. We hypothesize EDT survival has improved during the last 4 decades, and outcomes stratified by pre-hospital cardio pulmonary resuscitation(CPR), and injury patterns will provide benchmarks for success-to-rescue and survival outcomes for patients in extremis.

Study Design—Consecutive trauma patients undergoing EDT from 1975–2014 were prospectively observed as part of quality improvement. Predicted probabilities of survival were adjusted for prehospital CPR, mechanism of injury, injury pattern, patient demographics, and time period of EDT using logistic regression. Success to rescue (STR) was defined as return of spontaneous circulation with blood pressure permissive for transfer to the operating room.

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Results—1708 EDTs were included, with an overall 419 (24%) success to rescue and 106 survivors (6%). 1394 (79%) of these patients had pre-hospital CPR, 900 (54%) had penetrating wounds. The most common injury patterns were chest (29%), multi system with head (27%) and multisystem without head (21%). Penetrating injury was associated with higher survival than blunt trauma (9% vs 3% $p<0.001$). STR increased from 22% in 1975–1979 to 35% over the final 5 years ($P<0.001$); while survival increased from 5% to 14% ($p<0.001$).

Conclusions—EDT outcomes have improved over the past 40 years. In the last 5 years, STR was 35% and overall survival was 14%. This prospective observational data provides benchmarks to define the role of EHC as an alternative approach for patients arriving in extremis.

Introduction

Emergency department thoracotomy (EDT) has been employed for half a century to salvage trauma patients arriving in circulatory arrest. Early pioneers of this procedure from Ben Taub appreciated the therapeutic role of a thoracotomy for patient's who develop circulatory arrest from penetrating chest trauma irrespective of location in the hospital(1). This concept was expanded to blunt trauma patients with reportedly high salvage rates in the late 1970's(2). However, widespread adoption of this procedure in all trauma patients presenting to the emergency department in circulatory arrest was regarded as an "indiscriminate fire drill"; it was proposed that there should be specific indications(3). In 2000, a literature review of 4,000 trauma patient undergoing EDT reported a survival rate of 7.4% (4). A decade later, however, Passos et al (5) reported a dismal survival rate of 2.4% in their 17-year experience, and had concluded that this procedure was risky, expensive, and offered no survival benefit. Other investigators previously expressed concerns that the EDT risk and cost did not outweigh its potential benefits(6, 7). This negative opinion of EDT is reflective of the current status of this procedure at a national level. In an evaluation of five major level I trauma centers between 2006–2010, EDT was performed in only 13% of patients when indicated(8). Our analysis of the collective experience in the US indicates EDT survival rates vary from 35% for cardiac wounds, 14% for penetrating wounds, to 2% for blunt trauma(9).

There is a clear need for improving early hemorrhage control in trauma as this represents 40% of preventable deaths(10), and the median time to death in hypotensive patients is 2 hours from injury(11). The reported under utilization of EDT at level 1 trauma centers is concerning, as prehospital care, resuscitation, and operative interventions have improved. Hospitals that specialize in high-risk elective surgery such as cardiothoracic(12) and pancreatic(13) surgery have better outcomes when contrasted to low volume centers. An important component attributed to improved outcomes in these patients at high volume centers is that low volume centers have a higher rate of "failure to rescue" patients from postoperative complications(14). Trauma surgery has the reverse sequence; the patient must be rescued from circulatory arrest with an EDT before they can proceed to the operating room. This can be considered "success to rescue". It has been argued that trauma level designation, based on hospital resources and not volume, determines outcomes in trauma surgery(15, 16). However, these studies do not account for success to rescue from circulatory arrest because most of these centers consider a trauma patient in circulatory arrest dead on arrival (DOA).

The clinical implementation of minimally invasive hemorrhage control through resuscitative endovascular balloon occlusion of the aorta (REBOA)(17), has introduced an alternative strategy to augment resuscitation in patients with circulatory arrest following trauma. REBOA, in theory, could improve resuscitation efforts in trauma centers that fear the risks of EDT or lack experience in the technique. However, before global adoption of this technique, it is essential to benchmark the outcomes of EDT at high volume level I trauma centers' to identify the contemporary expected success to rescue patterns of trauma patients in circulatory arrest. We hypothesize that anatomic injury location and prehospital circulatory status are associated with markedly different success to rescue and survival rates in trauma patients undergoing EDT, and that overall survival rates have improved over time.

Methods

Patient Population

This prospective observational study includes continuously collected variables on all trauma patients presenting to our urban adult level I trauma center who underwent EDT from January 1975 to December 2014. Data acquisition was under the approval of the Colorado Multiple Institution Review Board. The purpose of this data collection was for quality improvement in refining the indication for this procedure to improve outcomes. The senior author (EEM) reviewed in real-time all patient prehospital characteristics and patient outcomes.

Patient Characteristics and Outcomes

Recorded patient demographics included age and sex. Prehospital variables included injury mechanism and anatomic location, in addition to detection of prehospital cardiac activity, and prehospital cardiopulmonary resuscitation (CPR). For this study, success to rescue was defined as return of spontaneous circulation (ROSC) and transfer of the patient to the operating room; by institutional protocol a systolic blood pressure greater than 70 mmHg was necessary. Outcomes reviewed included success to rescue and survival to hospital discharge. Neurologic outcome was scored using the Glasgow Outcome Score (GOS)(18) and was determined based on the most recent outpatient follow-up visit with rehabilitation if the patient left the hospital with neurologic impairment.

Statistical Analysis

SAS software version 9.4 (Cary, North Carolina) was used for statistical analysis. Continuous variables were described as medians with 25th to 75th percentile range (IQR) if the distribution was skewed or mean with standard deviation when data were normally distributed. Univariate analysis was performed using Kruskal-Wallis, Wilcoxon or Spearman correlation tests for continuous variables, and Chi-square or Fisher Exact test for categorical variables. The Cochran-Armitage test was used to assess temporal trends. Multivariate analysis to determine predicted probability of survival used logistic regression to adjust for clinically relevant variables (prehospital CPR, blunt versus penetrating mechanism, age, sex, and five-year period during when injury occurred). Model performance was evaluated using the area under the receiver operating characteristics curve

(AUROC) with 95% confidence intervals (discrimination) and the Hosmer-Lemeshow statistics (calibration, the larger the p-value, the better the fit).

Results

Patient Population and Injury Patterns

During the 40-year study period, 1,708 patients underwent an EDT at Denver Health Medical Center (DHMC). DHMC is an American College of Surgeons Committee on Trauma and state designated level 1 trauma center. The median age was 30 years (IQR 23–43); 81% of patients were men, and 79% underwent prehospital CPR. Temporal trends can be appreciated in table 1. Overall survival rate was 6.2%. Penetrating wounds occurred in 52% of patients and 59% of patients had multisystem trauma. The chest was the most common injury location (77%) followed by abdomen (49%), head/neck (37%) and extremity (37%). Isolated chest injuries represented nearly one-third of all patients, while isolated extremity was the least common in 0.8% (Figure 1).

Temporal Trends

The average number of EDT per year decreased during the study period (Table 2). In the first five years of the study period, 50.4 patients per year underwent EDT compared to the last five years when EDT averaged 35 per year. The peak rate of EDT was during 1985–1989 when 57 patients per year received this procedure. This rate markedly dropped over the next five-year time frame to 39 patients per year.

The percentage of men undergoing EDT significantly increased over time ($p=0.003$ table 1) from 78% during the first five years to 87% in the most recent five years. The percentage of patients undergoing prehospital CPR did not change significantly over time ($p=0.219$ table 1), but injury patterns of patients undergoing this procedure changed over time. Penetrating wounds tended to increase over time ($p=0.052$). Multisystem injuries were present in 68% of patients during the last five years compared to 49% in the first five years ($p<0.001$) and reflects an increase in the number of patients with thoracic ($p<0.001$), abdominal ($p=0.004$), and extremities injuries ($p<0.001$) but no difference in head injuries ($p=0.835$).

Outcomes

Success to rescue—There were 419 patients (24.5%) that had success to rescue. Of the 419 patients who arrived in the operating room, 147 (35%) survived to intensive care unit admission. Of the 147 who survived the OR 106 (72%) survived their hospitalization. The unadjusted success to rescue increased over time from 22% in 1975–79 to 35% in 2010–2014 ($p=0.001$). After adjusting for other predictors (pre-hospital CPR, age, sex, penetrating mechanism, and injury patterns), success to rescue during the study period increased ($p<0.0001$), especially in the last five years (OR=2.5, 95% CI: 1.5–4.2) compared to 1975–79. This model had good discrimination (AUROC 0.78 95% CI: 0.75–0.80) and calibration (H-L, $p=0.3778$). The percent of patients who survived the OR did not change over time ($p=0.743$). Among patients who survived the OR after EDT, there were no differences in age, sex, or pre-hospital CPR between those who survived the hospital stay and those who died in the intensive care unit.

Overall survival—Survival significantly increased over time ($p<0.001$) from 5% in 1974–79 to 14% in 2010–2014 (Figure 2). Injury patterns and pre hospital had were associated with wide range of survival patterns (Figure 3). Patients that survived to leave the hospital, were significantly more likely to have a thoracic injury (with or without other injuries, $p=0.004$). Survival patterns for isolated abdominal trauma ($p=0.885$), and multisystem trauma ($p=0.149$) did not increase over time, while survivors with isolated chest injuries ($p=0.002$) improved overtime. Nevertheless, when controlling for presence of thoracic injuries survival significantly improved over time ($p=0.019$). The largest improvement in survival was observed in patients with blunt trauma over the last five years that surpassed survival rates in penetrating injuries (Table 2). With further stratification of the injury mechanism, patients with stab wounds had the highest survival rates (Figure 4).

Defining benchmarks—Patients with prehospital CPR had a crude survival rate of 10% compared to patients without CPR who had a 3-fold improvement in survival at 34%. Survival improved over time, regardless of whether the patient underwent prehospital CPR ($p=0.022$) or not ($p<0.001$). Survival based on injury pattern and the effect modification of pre hospital CPR can be appreciated in Figure 3. The overall survival model had good discrimination (AUROC 0.80, 95%CI: 0.75–0.84) and calibration (Hosmer-Lemeshow statistics $p=0.92$).

Long-term outcome—Of the survivors, 68% had a no permanent neurologic deficits and 12% had mild neurologic disability based on GOS scoring(18). The remaining 20% were in a persistent vegetative state ($n=17$), died outside of the hospital ($n=2$) or were lost to follow-up ($n=2$).

Discussion

Emergency department thoracotomy for circulatory arrest from trauma remains a life saving procedure. In our high volume trauma center with routine performance of this procedure, survival has significantly improved over time. While the rate of EDT has decreased over time, suggesting improved patient selectivity, additional factors are likely responsible for the improvement in outcomes. There is a clear survival benefit of this procedure in patients with penetrating thoracic injuries. However, recovering from circulatory arrest for abdominal injuries remains a challenge. In addition to anatomic injury patterns, requiring prehospital CPR is associated with a significant decrease in survival. Interestingly, survival from blunt trauma has increased over the past 5 years. In the modern era of this procedure at our institution one in three patients is successfully resuscitated with a thoracotomy in the emergency department, and overall 14% of these patients survive with good neurologic outcomes.

The overall survival pattern in these patients is consistent with previously reported literature for penetrating chest injuries (4, 8, 19) and signs of life/no pre hospital CPR (6, 20–22). However, nearly 80% of trauma patients had CPR prior to EDT. It has been validated by our center(23) and in multicenter evaluation(24) that trauma patients with penetrating wounds undergoing less than 15 minutes of prehospital CPR can be salvaged with good neurologic outcomes. While EDT performed for isolated head/neck or extremity injury had high

survival percentages (Figure 3), those patients that survived with isolated head injuries remained in persistent vegetative states. All of the patients with blunt isolated head/neck injuries had suspicion for polysystem trauma, which were confined to the head and neck after imaging or exploration in the operating room. While EDT performed for non torso trauma has previously been reported to be successful (25), the role in isolated head remains unclear; importantly, none of these patients had gun shot wounds. Interestingly blunt trauma improved during the last five years of this study. The largest change in patient care over the past five years has been related to early plasma and goal directed resuscitation(26). Prospectively data indicates that early plasma and not necessarily the ratio of blood products improves survival(27). Plasma has been shown in vitro to not only improve coagulation but buffer fibrinolysis and metabolic derangements(28), which are essential in a patient in extremis. While this hypothesis requires additional investigation, improvement in patient selection has also played a role.

Refining patient selection to improve the cost effectiveness of this procedure has been an ongoing emphasis in an effort to reduce health care cost (4, 7). In fact, our group was the first to raise this issue in 1979 (3), and again 15 years ago [28]; we suggested that optimizing EDT outcomes could be associated with a 32% reduction in procedures with the same number of survivors(29). In this previous report EDT rates were 41/yr over a 23-year period. This rate has dropped by 26% over the last 5 years compared to our prior publication, and there has been an associated increase in survival from 4.4% to 14%. A marked reduction in presumably futile EDT in the late 1980's is illustrated in Figure 2 and Table 2. This selectivity also coincides with the increased concerns for risk of iatrogenic transmission of human immunodeficiency virus (HIV) from sharp instruments (30). The risks of iatrogenic self injury cannot be ignored with this procedure; the sero-conversion of blood borne pathogens from this procedure is estimated to be 1 in 1000 cases(31). Providers should be aware of this risk, and coordinated efforts to minimize accidental inflicted injuries including a pre-established role of care providers.

Regionalization of high-risk elective surgery has been shown to improve patient outcomes(12, 14). This should translate in trauma, however, it has been reported that trauma level status, and not trauma volume, correlates to outcome(15). The problem with this conclusion is that not all seriously injured patients are at high risk of death from hemorrhage. Injury severity does not take into consideration the patients physiologic status and active bleeding. It is important for a level I trauma center to be capable of gaining rapid hemorrhage control as 40% of trauma deaths are attributed to hemorrhage and considered to be the most common cause of preventable death(10). EDT and REBOA are complementary in achieving this goal, but should be applied to the appropriate patient for optimal outcomes.

Previous studies have not reported success to rescue from circulatory arrest as a potential outcome for quality measures. The importance of this marker on hospital performance is twofold: 1) reflective of the trauma surgeons ability to control life threatening hemorrhage and 2) provides a frame work for the future refinement of resuscitation strategies of patients with previously presumed lethal injuries which in the future may be amenable to advanced techniques such as extracorporeal circulatory support(32) or suspended animation(33). The EDT success to rescue rate has potential to be considered a benchmark for outcomes at level

I trauma centers, and could assist in developing optimal trauma systems. Prospective studies are warranted to investigate if level 1 trauma centers should also be designated as a high performing EDT center (based on success to rescue) to help guide EMS services triage critically injured patients for improving patient outcomes. These studies should include cost analysis, number of productive years lost, and survivor quality of life assessments. EDT performance has implication for policy reform. Trauma level designation at the state and national level of level I trauma centers could be set at a minimum requirement for success to rescue from circulatory arrest. This is particularly timely with the respect to ACS/COT position that level II trauma centers provide equivalent care to level I. Our recent geospatial analysis of Colorado indicates that there are too many high-level trauma centers.

In reality, if no patients in traumatic arrest underwent an EDT and were declared dead on arrival (DOA), there would be a reduction in cost to the hospital as well as valuable resources such as blood products, ED and OR time. However, in the modern era, if a high volume center can rescue 1 in 3 trauma patients from circulatory arrest and have an overall 14% survival rate, the cost is justified. As technology improves patients who survive to the OR are likely to have improved overall survival in the future. By forgoing this life saving procedure, advances in trauma will be limited to the most severely injured patients undergoing attempted resuscitation. Furthermore, there are potential benefits to society by providing viable organs for transplantation(34).

REBOA has been implemented as an alternative to EDT(17), but the precise role remains to be defined(35) REBOA is a rational approach for select patients, and success has been impressive, particularly with bleeding from major pelvic fractures (36). However, the technique must be learned systematically as complications reported from Japan(37) have been concerning. We believe it is imperative for all trauma surgeons in level I trauma centers to be trained to perform REBOA as well as EDT. Future prospective studies contrasting EDT to REBOA with well-matched patients based on injury patterns and prehospital physiologic parameters are essential.

In conclusion, hemorrhage is the most common cause of preventable death of young individuals in the United States. Benchmarking trauma centers on success to rescue may help delineate high performing centers and better define a needs base assessment of regional trauma systems. We submit EDT remains the gold standard for thoracic trauma and REBOA should be considered as an alternative approach for abdominal and pelvic injuries, however these indications need to be established by randomized control trials.

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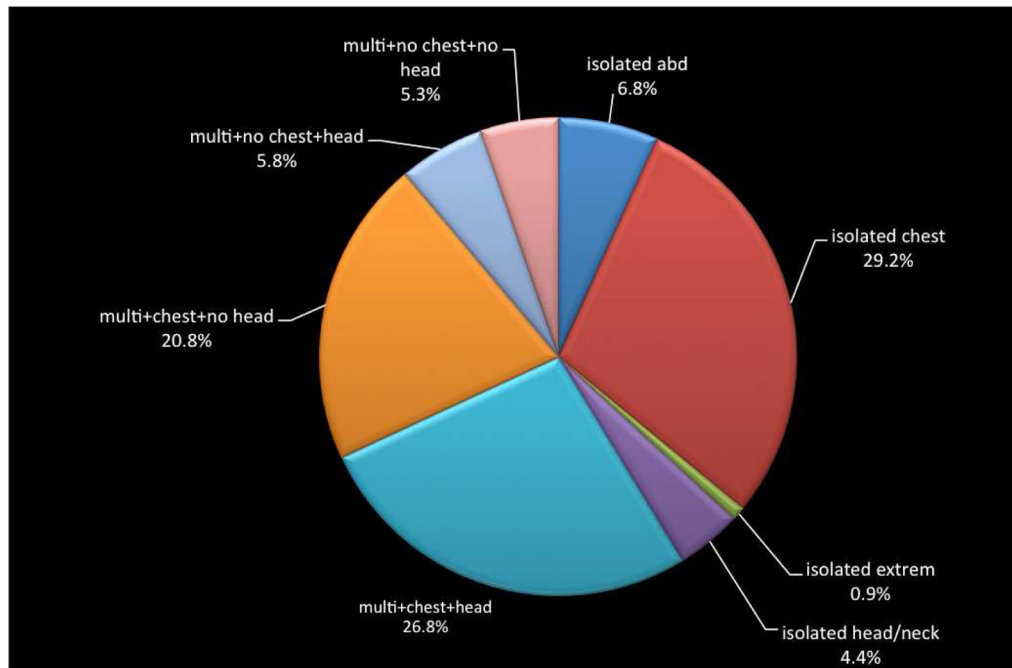


Figure 1. Distribution of injuries of patients undergoing emergency department thoracotomy during the study period. abd, abdominal injury; multi, multiple system trauma; extrem, extremity injury.

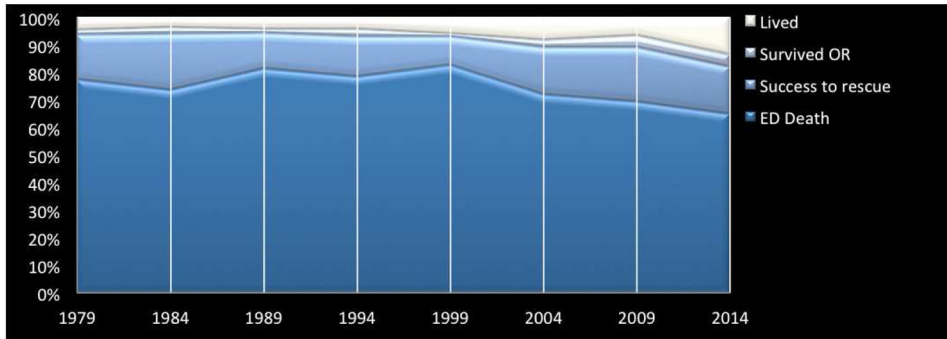


Figure 2. Changes in outcomes of emergency department thoracotomy over time. The percent of total patients per outcome are summed to 100% on the Y axis over 5-year intervals, which are displayed on the X axis and progress from the earliest study time point on the left to the most recent study period on the right. abd, abdomen; CPR, cardiopulmonary resuscitation; ED, emergency department; extrem, extremity injury; OR, operating room; Success-to-rescue, return of spontaneous circulation with systolic blood pressure of greater than 70 mmHg and transfer to operating room; Survived OR, survived first operative procedure and successfully transported to the intensive care unit postoperatively.

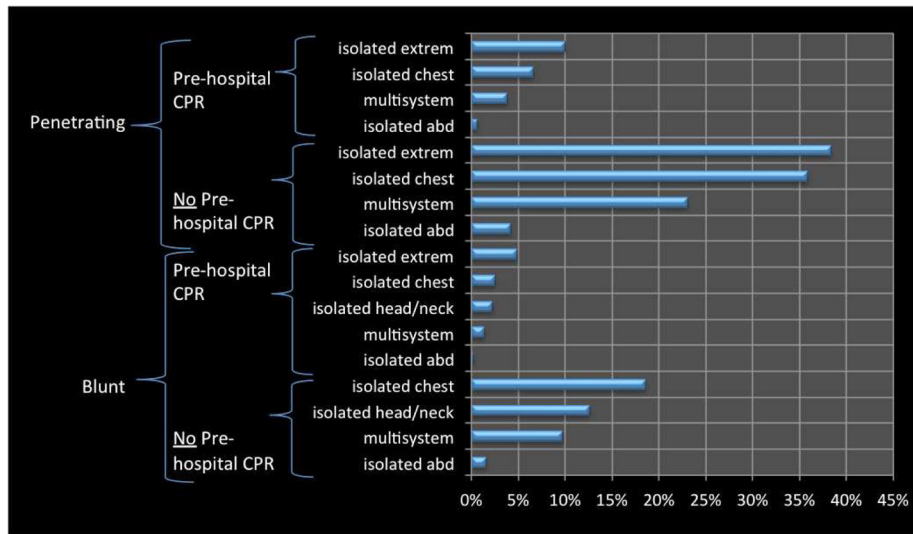


Figure 3. Percent survival of patients based on injury pattern and blunt vs penetration trauma. CPR, cardiopulmonary resuscitation; extreme, extremity injury; abd, abdominal injury; multisystem, injuries to multiple body regions.

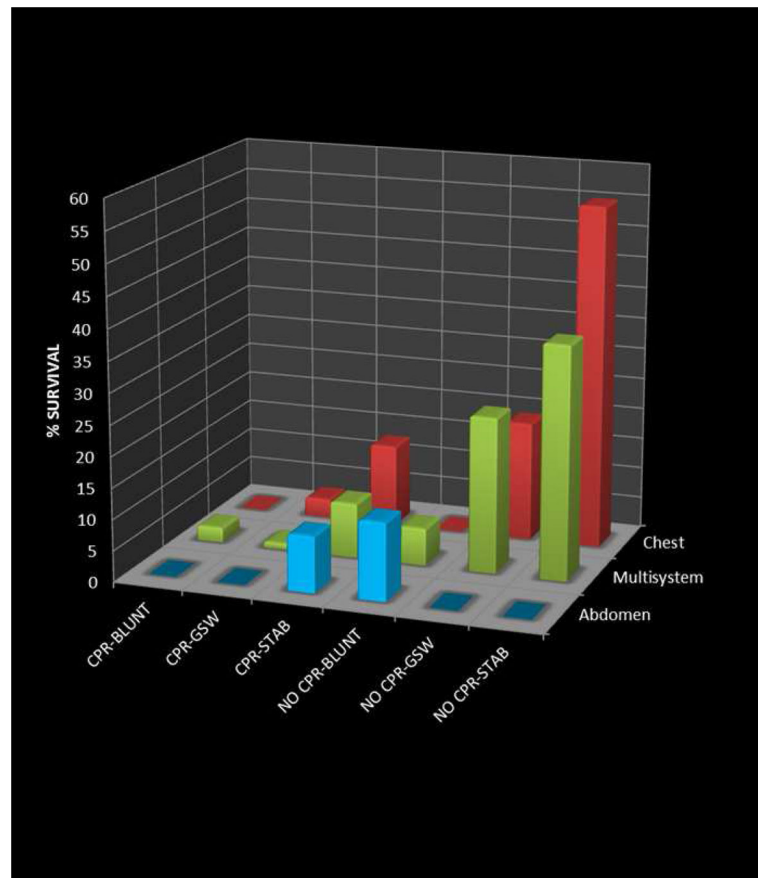


Figure 4. Three-dimensional survival patterns based off of injury mechanism, location, and undergoing pre-hospital cardiopulmonary resuscitation (CPR). BLUNT includes: motor cycle crash, motor vehicle crash, and auto-pedestrian; GSW, gunshot wound; STAB, stab injury.

Table 1

Trends in Patient Demographics and Injury Patterns over Time

	1975-1979	1980-1984	1885-1989	1990-1994	1995-1999	2000-2004	2005-2009	2010-2014
n	252	258	287	194	184	192	164	177
Demographics								
Median age, y	28	29	32	30	29	31	28	34
IQR	22-41	23-39	22-45	22-42	21.5-43	23.5-42.5	22-42.5	24-47
Male sex								
n	198	209	221	150	151	166	138	131
%	78.6	81.0	77.0	77.3	82.1	86.5	84.7	87.3
Injury characteristics								
Penetrating								
n	146	116	122	113	105	108	107	88
%	57.9	45.0	42.5	58.3	57.1	56.3	65.2	49.7
Treatment, pre-hospital CPR								
n	209	203	227	156	144	143	130	120
%	82.9	78.7	79.7	80.8	78.3	74.5	79.8	79.0

Table 2

Trends in Emergency Department Thoracotomy Outcomes over Time

Quin-quennial, 5-y	EDT/y, average	Success-to-rescue, %	Survive OR, %	Penetrating survivors, %	Blunt survivors, %	Survivors per 5 y, n	Overall survival, %
1975-79	50	23	6	8	1	12	5
1980-84	52	27	6	6	2	10	4
1985-89	57	19	6	7	3	13	5
1990-94	39	22	7	7	3	9	5
1995-99	37	17	7	9	3	11	6
2000-04	38	28	10	13	2	16	8
2005-09	33	30	10	8	4	11	7
2010-14	35	35	18	13	15	24	14

EDT, emergency department thoracotomy.