Defining the optimal time to the operating room may salvage early trauma deaths

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BACKGROUND: Early trauma deaths have the potential for salvage with immediate surgery. We studied time from injury to death in this group to qualify characteristics and quantify time to the operating room, yielding the greatest opportunity for salvage.

METHODS: The Pennsylvania Trauma Outcomes Study (PTOS) is a comprehensive registry including all Pennsylvania trauma centers. PTOS was queried for adult trauma patients from 1999 to 2010 dying within 4 hours of injury. The distribution of time to death (TD) was examined for subgroups according to mechanism of injury, hypotension (defined as systolic blood pressure ≤ 90 mm Hg), and operation required. The 5th percentile (TD5) and the 50th percentile (TD50) were calculated from the distributions and compared using the Mann-Whitney U-test.

RESULTS: The PTOS yielded 6,547 deaths within 4 hours of injury. The overall TD5 and TD50 were 0:23 (hour:minute) and 0:59, respectively. Median penetrating injury times were significantly shorter than blunt injury times (TD5/TD50, 0:19/0:43 vs. 0:29/1:10). Median time was significantly shorter for hypotensive versus normotensive patients (TD5/TD50, 0:22/0:52 vs. 0:43/2:18). Operative subgroups had different TD5/TD50 (abdominal surgery [n = 607], 1:07/2:26; thoracic surgery [n = 756] 0:25/1:25; vascular surgery [n = 156], 0:35/2:15; and cranial surgery [n = 18], 1:20/2:42).

CONCLUSION: Early trauma deaths have the potential for salvage with immediate surgery. We found TD to vary based on mechanism of injury, presence of hypotension, and type of surgery needed. With the use of TD5 and TD50 benchmarks in these subgroups, a trauma system may determine if decreased time to the operating room decreases mortality. Trauma systems can use these data to further improve prehospital and initial hospital phases of care for this subset of early death trauma patients. (*J Trauma Acute Care Surg*. 2014;76: 1251–1258. Copyright © 2014 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level III.

KEY WORDS: Trauma; early death; time to surgery; trauma system; benchmark.

Optimal trauma care requires time-sensitive interventions. Some circumstances require the lifesaving intervention to be a surgical procedure in an operating room (OR). Trauma systems during the past 40 years have developed around the concept of bringing the trauma patient to the trauma center in the most expeditious manner possible and within a 1 hour time frame known as the "golden hour." Thus, most trauma system experts use the golden hour as a rule of thumb when planning prehospital care and transport. Although a convenient number with which to plan, it has little scientific basis.[1]

In addition, the classic "trimodal" distribution of trauma deaths defined as deaths at the scene, early deaths, and late deaths[2] and results of the Major Trauma Outcomes Study (MTOS)[3] have framed trauma system planning during the past 40 years. For the "early death" group of patients, we still lack a time frame within which we should have a trauma patient in the trauma center's fully staffed and equipped OR. Preventable trauma death studies continue to show that there is a subgroup of early deaths that might benefit from a more rapid or direct transport to an OR for survival.[4] It is also known that the overall distribution of time to death (TD) varies based on environment, age, mechanism of injury, body region(s), and severity of injury.[5]

The subgroup of early death trauma patients is the focus of this work. This subgroup of deaths has the potential for salvage with rapid transport to a trauma center and with immediate surgery. The optimal time from injury to the OR for this subgroup of patients has not been fully elucidated, and therefore, these key times have not been available for trauma center and system planning as benchmarks for the most critical patients entering a civilian trauma system. Thus, we studied the time from injury to death for this early death subset of patients to qualify their characteristics and quantify the time to the OR, which gives the greatest potential for patient salvage.

PATIENTS AND METHODS

The Pennsylvania Trauma Outcomes Study (PTOS) is a well-established and comprehensive trauma registry including all accredited trauma centers in the state. PTOS was queried for all adult trauma patients between 1999 and 2010 with data on time of injury and death and who died within 4 hours of injury. The database does not include prehospital deaths. Individual trauma centers within PTOS are required to submit data within 90 days of discharge. Data on time of injury were obtained from the prehospital provider's note. Data time of death were obtained from hospital note on the time of death. Demographic data for the early death group and subgroups of patients were compared using Student's t test for continuous variables and χ^2 analysis for nominal variables.

To develop a useful benchmark for optimal time to operative intervention to maximize survival, we examined TD distributions. We defined TD as the difference between the time of death within the hospital subtracted from the time of injury. We assigned TD criteria when 50% (TD50 or median) and 95% (TD5) of patients were still living. We felt that these percentiles would yield the most practical end points. The median times (TD50s) were compared using the Mann-Whitney U-test ($p < 0.05$, two-tailed).

The distribution of TD was examined for the overall early death group as were subgroups of penetrating versus blunt injury, hypotension (defined as systolic blood pressure [SBP] < 90 mm Hg), death in the emergency department (ED), and operative groups (laparotomy, thoracic surgery, vascular surgery, and craniotomy). TD5 and TD50 timelines were created to visually depict these trauma system benchmarks. All calculations performed and all histograms created were performed using IBM SPSS Statistics 20 (IBM, Armonk, New York).

RESULTS

The PTOS database contained 412,768 patients for the time interval with 27,479 (6.7%) deaths. Death within 4 hours yielded 6,547 patients for analysis. The characteristics of the final early death study group are shown in Table 1. Overall, 63.8% were white, 32.3% were black, 1.2% were Asian, and 2.7% were listed as "other" or were unspecified (p < 0.000

TABLE 1. Characteristics of the Early Death Group

	Total Group	Penetrating	Blunt	*p*
Total number	6,547	2,533	4,014	
Total, %	100.0	38.7	61.3	
Age, y	42.6	33.9	48.1	<0.001*
Sex, male, %	77.0	90.1	68.7	<0.001*
Race, %				
Black	32.3	62.5	13.3	<0.001**
White	63.8	32.6	83.4	
Asian	1.2	1.4	1.0	
Other	2.7	3.4	2.3	
Hypotension (%SBP ≤ 90)	84.2	87.2	82.4	<0.001*
ISS, mean	33.2	34.4	31.8	0.423

*$p < 0.05$ considered significant difference.
**χ^2 analysis of race (black or white only) and mechanism of injury (penetrating or blunt).

when comparing white vs. black). When examining the penetrating injury group only, 62.5% were black and 32.6% were white compared with the blunt injury group, which had 13.3% black and 83.4% white. The overall group was 77% male, with 90% male in the penetrating group and 69% male in the blunt group ($p < 0.001$). The average age of the overall group was 42.6 years, with an average age of 33.9 years and 48.1 years ($p < 0.001$), respectively, for the penetrating and blunt groups. The percentages of patients presenting with hypotension (SBP < 90 mm Hg) for each subgroup were 87.2% in the penetrating group and 82.4% in the blunt group. The average Injury Severity Score (ISS) for the overall group was 33.2, and there was no statistically significant difference between penetrating and blunt ISS.

The overall population TD5 and TD50 was 0:23 (hour: minute) and 0:59, respectively (Fig. 1). Median penetrating injury TDs were significantly shorter than blunt injury times (Fig. 2), with TD5/TD50 being 0:19/0:43 versus 0:29/1:10, respectively ($p < 0.001$). Median time was significantly shorter in the overall group for hypotensive versus nonhypotensive patients (Fig. 3), with TD5/TD50 being 0:22/0:52 versus 0:44/2:18, respectively ($p < 0.001$). When evaluating the penetrating group only, median TDs were significantly shorter in the hypotensive penetrating group versus the nonhypotensive penetrating group, with TD5/TD50 being 00:19/00:39 versus TD5/TD50 = 00:37/1:57, respectively ($p < 0.001$). When evaluating the blunt group only, median TDs were significantly shorter in the hypotensive blunt group versus the nonhypotensive blunt group, with TD5/TD50 being 00:27/01:01 versus 00:52/2:27, respectively ($p < 0.001$) (Fig. 4).

Of the overall study group, 76.9% died in the ED, 18.8% died in the OR, and 4.2% died in the intensive care unit. TD5/TD50 for patients who died in the ED was 0:22/0:47 (Supplemental Digital Content 1, http://links.lww.com/TA/A399). The mean and median admission SBPs in this group were 19 mm Hg and 0 mm Hg, with 82.7% of the patients having an initial SBP of 0 mm Hg (Supplemental Digital Content 2, http://links.lww.com/TA/A400). The group of patients who died in the ED had a mean ISS of 31.0. The group of patients reaching the OR had TD5/TD50 of 1:00/2:23 (Supplemental Digital Content 3, http://links.lww.com/TA/A401). The mean and median admission SBPs in this group were 59 mm Hg and 67 mm Hg, with 38.5% having an admission SBP of 0 mm Hg (Supplemental Digital Content 4, http://links.lww.com/TA/A402). The group of patients who died in the OR had a mean ISS of 36.7 ($p < 0.001$ when compared with those who died in the ED). The distribution of SBPs between those who died in the ED and those who died in the OR was significantly different ($p < 0.001$).

Operative subgroups had the following TD5/TD50: abdominal surgery (n = 607), 1:07/2:26 (hypotensive laparotomy group, 1:06/2:28 vs. nonhypotensive laparotomy group, 1:08/2:26; $p = 0.692$) (Supplemental Digital Content 5, http://links.lww.com/TA/A403); thoracic surgery (n = 756), 0:25/1:25 (hypotensive thoracic surgery group, 0:24/1:09 vs. nonhypotensive thoracic surgery group, 0:40/2:10; $p < 0.001$) (Supplemental Digital Content 6, http://links.lww.com/TA/A404); vascular surgery group (n = 156), 0:35/2:15 (hypotensive vascular surgery group, 0:32/2:09 vs. nonhypotensive vascular surgery group, 1:14/2:31; $p = 0.014$) (Supplemental Digital Content 7, http://links.lww.com/TA/A405); and cranial surgery (n = 18), 1:20/2:42. The cranial surgery early death group was too small to allow further practical evaluation between the hypotensive and nonhypotensive groups.

DISCUSSION

The optimal time from injury to the OR in trauma is unknown. Early deaths upon arrival to trauma centers have the potential for salvage if surgery is immediate. We studied the time from injury to death for this subset of trauma patients to qualify the characteristics and quantify the time to the OR, which might yield the greatest potential for patient salvage. For a trauma system to have the potential to save 95% of early deaths, we observed that most of these patients must be in the OR within 23 minutes after injury. We also observed that the necessary time varies with the mechanism of injury, hypotension,

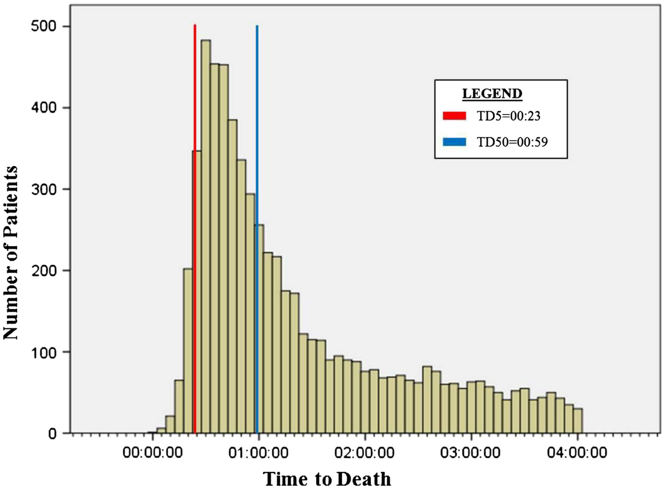

Figure 1. TD for all early deaths. Note the distribution of TD within the early death study group and the time for TD5 and TD50.

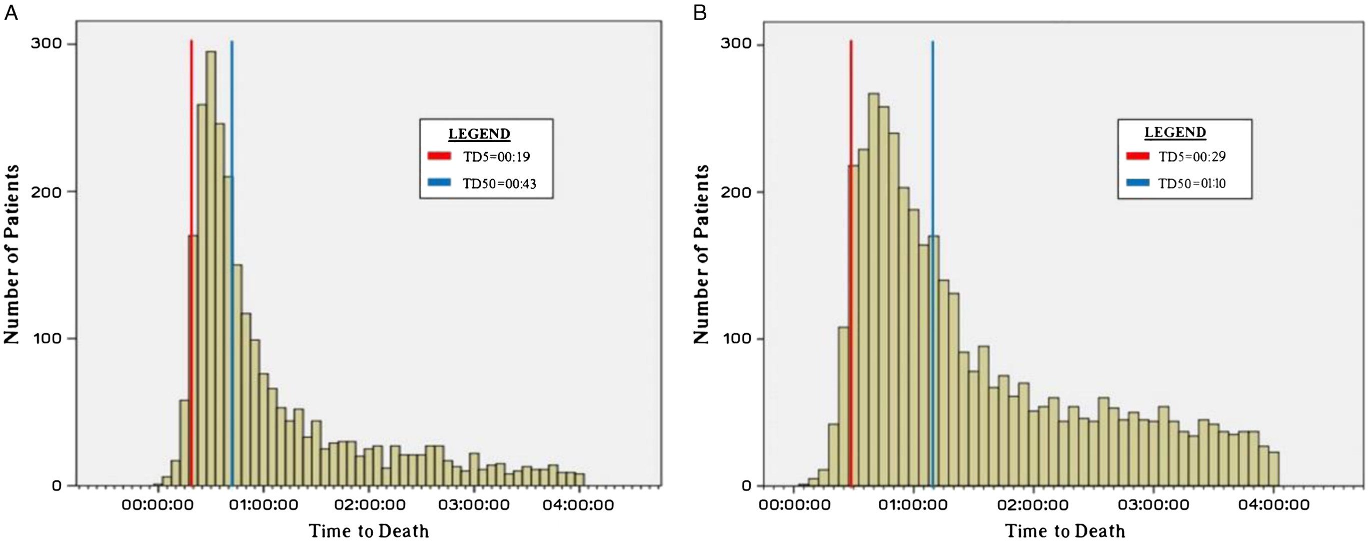

Figure 2. TD by mechanism of injury. *A*, TD for the penetrating early death group. *B*, TD for the blunt early death group. Note the difference in TD5 and TD50 between the penetrating and the blunt subgroups of early death trauma patients.

and body cavity requiring surgery. The times required to meet the 95% goal are significantly shorter for the subgroups of patients with penetrating injury (19 minutes), hypotension (22 minutes), penetrating injury and hypotension (19 minutes), and requiring thoracic (25 minutes) or vascular surgery (35 minutes). In addition, patients who died in the ED had significantly lower initial SBPs recorded (82% had a 0 recorded as their initial blood pressure) compared with those who were able to make it to the OR. We did not find a statistically significant difference in TD between hypotensive and nonhypotensive patients requiring laparotomy. Finally, we could not determine how many patients in the thoracotomy subgroup had an ED thoracotomy first from PTOS data, but we observed that 61.1% (61 of 108) of similar patients did have an ED thoracotomy before formal thoracotomy in our single-center experience.

We sought previous work examining mortality, mechanism and type of injury, and times with which to compare our outcomes. In the classic Major Trauma Outcomes Study (MTOS) by Champion et al.,[3] severity of injury was correlated with outcomes to provide a benchmark with which trauma centers could compare their individual outcomes. This concept revolutionized trauma outcomes research at the systems level. Our study attempts to also provide a benchmark with which to compare trauma mortality, but instead of comparing trauma scores, we compare TDs by mechanism and physiology for use in trauma system planning.

In a more recent classic study, Demetriades et al.[5] studied 4,151 trauma deaths in Los Angeles County during a 3-year period and analyzed deaths based on the most severe injury (Abbreviated Injury Scale [AIS] score ≥ 4) to the head, chest,

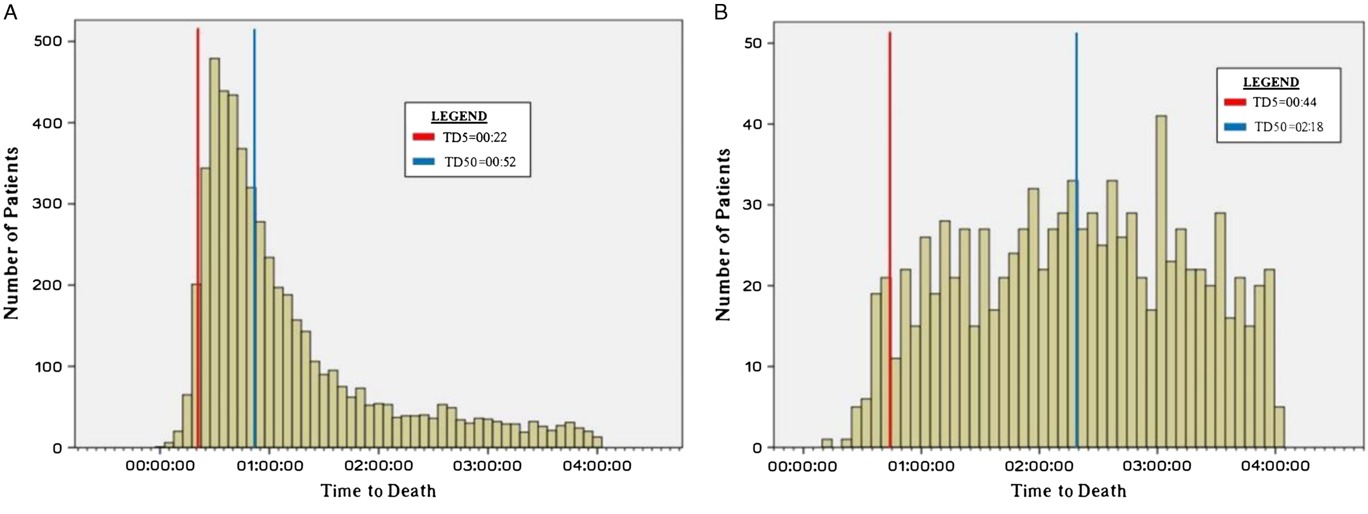

Figure 3. TD by blood pressure. *A*, TD for the hypotensive subgroup (SBP < 90 mm Hg). *B*, TD for the nonhypotensive subgroup (SBP ≥ 90 mm Hg). Note the difference in TD5 and TD50 between the two subgroups.

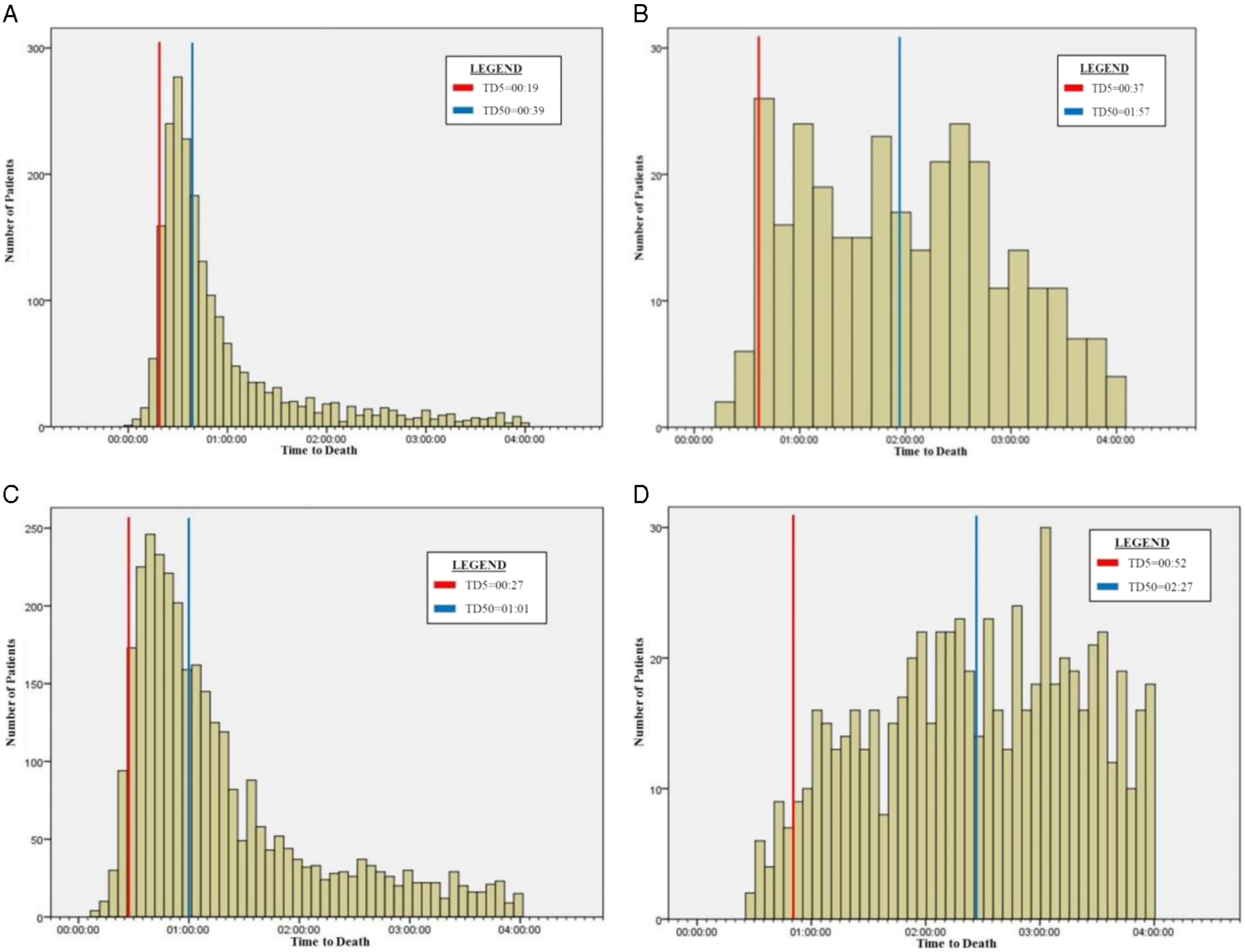

Figure 4. TD by mechanism of injury and by blood pressure. The combinations of TD by mechanism and by presence or absence of hypotension. TD5 and TD50 are earlier with the combination of penetrating injury and hypotension. *A*, Penetrating and hypotensive. *B*, Penetrating and nonhypotensive. *C*, Blunt and hypotensive. *D*, Blunt and nonhypotensive.

abdomen, and extremity to determine if the classic "trimodal distribution" of death occurred in their mature trauma system. They found that this classic description no longer exists in their system. They analyzed time intervals of less than 1 hour, 1 hour to 6 hours, 6 hours to 24 hours, 1 day to 3 days, 3 days to 7 days, and more than 7 days and found different TD distributions based on the injured body region. The penetrating injury group had by far the largest peak of death within the first hour, and blunt injury not only had a large initial peak but also had a second peak at 1 day to 3 days no third peak of death. Severe chest trauma (AIS score ≥ 4) also demonstrated a high first peak of death within 1 hour. Severe head trauma (AIS score ≥ 4) had a large first hour peak, but less severe head injury (AIS score < 4) demonstrated no mortality peaks. The authors conclude that early surgical intervention may provide a greater salvage for these patients with early death. This study was unique in that it developed mortality curves based on injury locations and AIS. Time intervals were created to compare findings with the classic trimodal distribution of death. The study did not look specifically at early trauma deaths or break down times in a continuous manner to focus on the early death time interval.

A study by MacLeod et al.[6] was conducted in patients who arrived in extremis and examined preventability. Their analysis suggested that there is a subgroup of patients in extremis who die within the first hour of arriving in the hospital, and some of these are potentially preventable deaths. Their study found that patients in extremis who had a single organ or vessel injury without brain injury represented 38% of their sample. They advocated for aggressive resuscitation of these patients. This argues in favor of studying TD in the early death subgroup of patients with a focus on preventability as we have done in this study.

Several studies dealt directly with prehospital, ED, and operative times and with triage criteria. A meta-analysis by Carr et al.[7] described average prehospital transport and scene time for helicopter and ground ambulances in urban, suburban, and rural environments but did not link this to outcomes. They found average total prehospital times for urban, suburban, and

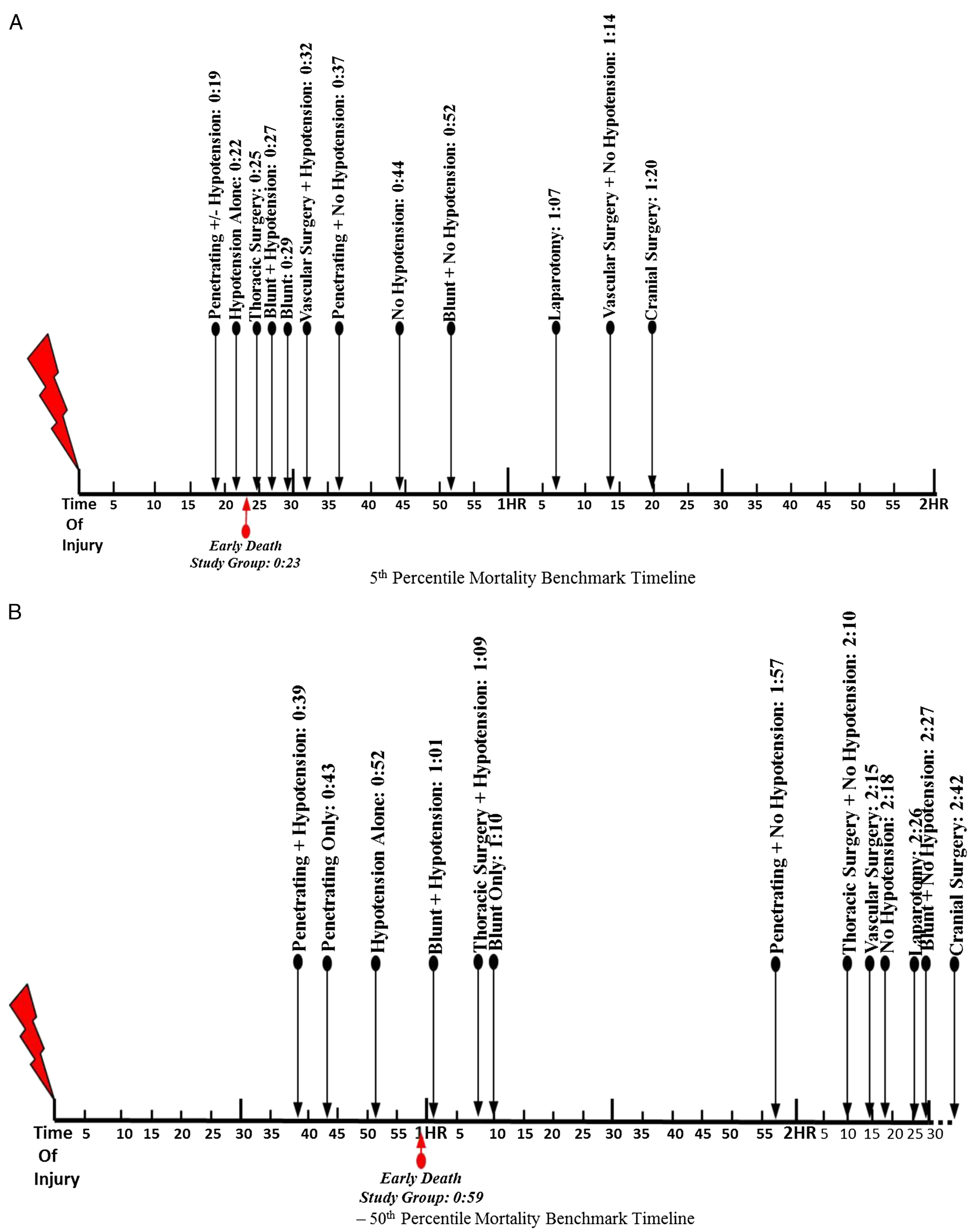

Figure 5. Mortality benchmark timelines. Note the chronologic positioning of early death groups by mechanism, type of surgery, and presence of hypotension. This timeline representation provides a visual display of the data for system planning.

rural locations to be 30.96, 30.97, and 43.17. Average helicopter ambulance times were 23.25 minutes for response, 20.43 minutes on scene, and 29.80 minutes for transport. Steele et al.[8] assessed whether the American College of Surgeons' prehospital trauma triage criteria predicted the need for an operation. They found that gunshot wound to the neck and torso predicted a need for operation with a likelihood ratio (LR) of 7.5, confirmed hypotension with an LR of 5.3, respiratory compromise with an LR of 2.9, and a Glasgow Coma Scale (GCS) score lower than 8 with an LR of 2.1.(10) Times were not studied in relation to the need for operation or outcome.

In their mature trauma system, Dutton et al.[9] noted that of all trauma mortality at their center, roughly 50% died of brain injury and 30% of exsanguination. Of those who died of exsanguination, the average TD from arrival at their trauma center was 2 hours. In a unique study of time to laparotomy for bleeding from trauma, Clarke et al.[10] described a 1% increase in mortality for every 3-minute delay in the ED for hypotensive (SBP < 90 mm Hg) trauma patients requiring a laparotomy. Lipsky et al.[11] examined prehospital blood pressure as a predictor for needed operative intervention. They found that patients who were hypotensive in the field had a three times higher likelihood of requiring an operative intervention.

From our military experience, the creation of a true theater of war trauma system has facilitated a more optimal organization of our surgical assets in the battlefield.[12] Initial damage-control surgery and resuscitation is provided at far forward surgical locations sometimes within minutes of the point of injury.[13] Although TD data for a similar early death group from the military experience are not available, early surgical intervention at forward surgical teams is likely one of the contributing factors to the lowest case-fatality rate in our history.[14]

Our data have implications for trauma system planning, trauma center preparedness, and prehospital triage criteria, and we draw several conclusions. First, for a trauma system to meet the expectation of having 95% of the patients in the OR within 23 minutes, the injured person most commonly must be in an urban environment within minutes of a trauma center. Second, the historical trauma system benchmark of 1 hour to a trauma center does not include 95% of early deaths (39 minutes) in this study but approaches the 50% mark of the early deaths (59 minutes). Third, the goal of adapting times based on potentially saving 50% of all the early deaths may be a more realistic benchmark for trauma system planning given the very short time intervals involved. This is especially applicable to an urban or suburban trauma system, and planners must recognize that a portion of these deaths are not preventable from a pathophysiologic and an anatomic perspective.

To translate our outcomes into usable trauma system benchmarks, we created a mortality timeline from the histograms for the 5th percentile and 50th percentile early deaths (Fig. 5). The timelines visually capture the essential outcomes of our time to early death study in a format useful for trauma system planning. For example, using the 50th percentile timeline, trauma system planners in Pennsylvania could set a benchmark of 40 minutes to the OR for all hypotensive patients with penetrating injury (based on actual time displayed in Fig. 5*B* of 39 minutes). Mortality in this subgroup of patients is then compared with a prebenchmark implementation. If a decrease in mortality is demonstrated, then this new benchmark should remain as a new standard of care.

Urban or rural specific data may ultimately be more useful for individual locations. For example, urban system planners may narrow the study population to Philadelphia and Pittsburgh and rural planners may exclude data from urban centers. This would provide location-specific time benchmarking data for planners. Similarly, the military could study early death time data from a theater of war to further optimize battlefield triage criteria and forward surgical team positioning.

There exist several limitations in interpreting our data. First, this is a study of the group of trauma patients who *died within 4 hours* and does not study patients that survived *because of the trauma system*. It is a TD version of a preventable death study for the trauma systems. Thus, we are only studying the most severely injured patients to attempt to find a potentially preventable death time for systems planning. The PTOS demonstrates a commendable mortality of only 6.7%, which is not highlighted in this study.

A second limitation is the availability of time data within PTOS. Only 38.9% of patients had the required time of injury or death entry requiring exclusion of more than 10,000 patients. Multiple imputation techniques would be difficult to apply to injury times that do not depend on other study variables and that determine the main study outcome (TD). Other times could have been substituted as proxies but would have confused outcomes. In addition, times were entered from prehospital records and were not synchronized to hospital time. In-hospital times of death can be subjective and vary by provider preference of length of resuscitation attempted. Despite eliminating more than 10,000 patients, we are still left with a large sample size over a 10-year period.

Third, the study of operative subgroups (laparotomy, thoracic surgery, vascular surgery, and cranial surgery) yielded subgroups of patients smaller than expected, indicating that these data may not be completely provided. The body region involved in relation to TD could improve triage criteria for prehospital providers. The depth of detail based on body region and AIS as done by Demetriades et al.[4] could not be replicated with our data.

Lastly, our analysis is limited by selection bias. Those who died in the ED died sooner than those in the OR and so were not analyzed under the OR group. Those who died in the prehospital setting and did not reach the hospital were not available to be included in this study. Those who were able to reach the OR for laparotomy were those who were able to be stabilized in the ED. Thus, when examining for a TD difference among hypotensive versus nonhypotensive operative patients, many of those who made it to the OR were probably not initially hypotensive on first blood pressure. This is likely a reason that there is no difference in mortality between the laparotomy hypotensive and nonhypotensive operative groups.

In this study, we were able to provide several clinical characteristics and quantify the benchmarks (times) for those patients requiring an immediate operation to potentially improve survival. Hypotensive patients who have some level of measurable blood pressure upon arrival seem to be the group of patients that could benefit the most from more rapid surgical interventions. TD timelines provide benchmarks for measuring the performance of trauma centers with this challenging group of patients. The information provided by TD benchmarks may direct system planners to question the prehospital model of care, triage, and transport directives as well as explore different initial ways to transiently stabilize patients and the criteria for direct admission to an OR in this early death subset of patients.

AUTHORSHIP

K.N.R. is the primary author and contributed to the literature search, study design, data collection, analysis and interpretation, and writing. C.W.S. contributed to the data analysis, interpretation, and critical revision. B.P.S. contributed to the data analysis, interpretation, and critical revision. A.M. contributed to the literature search, data collection, and analysis. P.K.K. contributed to the study design, data collection, interpretation, and critical revision. P.M.R. contributed to the data analysis, interpretation, and critical revision.

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