Hemorrhage is More Prevalent than Brain Injury in Early Trauma Deaths: The Golden Six Hours

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Abstract

Introduction: Under the trimodal distribution, most trauma deaths occur within the first hour. Determination of cause of death without autopsy review is inaccurate. The goal of this study is to determine cause of death, in hourly intervals, in trauma patients who died in the first 24 h, as determined by autopsy.

Materials and Methods: Trauma deaths that occurred within 24 h at a Level I trauma center were reviewed over a six-year period ending December 2005. Timing of death was separated into 0–1, 1–3, 3–6, 6–12 and 12–24 h intervals. Cause of death was determined by clinical course and AIS scores, and was confirmed by autopsy results.

Results: Overall, 9,388 trauma patients were admitted, of which 185 deaths occurred within 24 h, with 167 available autopsies. Blunt and penetrating were the injury mechanisms in 122 (73%) and 45 (27%) patients, respectively. Of 167 deaths, 73 (43.7%) occurred within the first hour. Brain injury, when compared to other body areas, was the most likely cause of death in all hourly intervals, but hemorrhage was as or more important than brain injury as the cause of death during the first 3 h and up to 6 h. No deaths were attributable to hemorrhage after 12 h.

Conclusions: The temporal distribution of the cause of death varies in the first 24 h after admission. Hemorrhage should not be overlooked as the cause of death, even after survival beyond 1 h. Understanding the temporal relationship of causes of early death can aid in the targeting of management and surgical training to optimize patient outcome.

Key Words
Trauma · Autopsy · Mortality · Hemorrhage · Brain injury

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Introduction

The trimodal distribution of trauma death is widely accepted and has become a standard paradigm for outcomes in trauma systems [1]. In this paradigm, most deaths (45%) occur within the first hour following injury and are a result of major brain or cardiothoracic injury. A second peak (24%), occurring within the next 4 h, is also thought to be a result of cardiovascular or neurological compromise. This second mortality peak has been targeted as being potentially preventable in causing death, and aggressive resuscitation and rapid intervention is thought to improve outcomes. The last mortality peak (20%), beyond one week, is secondary to sepsis and multisystem organ failure. Recently, the trimodal distribution of death has been challenged [2–4]. Meislin et al. [3] reported a bimodal distribution of deaths with one peak in the first 60 minutes following injury and a second peak at 24–48 h. In an analysis of 4,151 trauma deaths, Demetriades et al. [5] has shown a similar bimodal distribution of death, with most (50.2%) occurring within the first hour and a second peak (18.3%) occurring between the first and the sixth hour. These authors also found significantly fewer deaths (7.6%) after one week than initially described by Trunkey [1]. It is likely that the evolution of mature trauma systems, which have resulted in improved resuscitation, rapid radiology imaging, and prompt operative intervention, may be changing the temporal distribution of trauma deaths.

In this regard, a modern analysis of specific causes of early trauma deaths and their temporal distribution may provide useful information for trauma systems to reduce mortality and to better target manpower and resource utilization. The established causes of trauma deaths, determined solely by clinical findings, have been shown to be incorrect in up to 30% of cases [6, 7]. Post mortem results may further delineate the actual cause of death in trauma patients. The San Diego County Trauma System is unique, since most trauma deaths are reviewed by the San Diego Medical Examiner. Therefore, we hypothesize that the cause of early trauma mortality, as determined by autopsy, will vary significantly depending on the time elapsed from admission to death.

Materials and Methods

After obtaining Institutional Review Board approval, all trauma deaths that occurred within 24 h from arrival at a university Level I trauma center were reviewed for a six-year period beginning January 2000 and ending December 2005. As a San Diego County policy, all trauma deaths are reviewed by the San Diego County Medical Examiner. The full autopsy report was obtained and analyzed for all trauma deaths occurring within 24 h from admission, and all pertinent data were extracted. Deaths that occurred on the scene were excluded.

The time to death, defined as the time from admission to death, was separated into 0–1, 1–3, 3–6, 6–12 and 12–24 h intervals. Cause of death was determined by clinical course and AIS scores in several body areas, and was confirmed by the death certificate, the autopsy results and the final report as determined by the county coroner. After review, cause of death was grouped into six categories: brain, thorax, abdominal, peripheral vascular, pelvis, and other. Detailed data extracted on each patient also included demographic information, injury severity score (ISS), mechanism of injury, Glasgow coma scale (GCS), admission systolic blood pressure, and base deficit. A one-way analysis of variance (ANOVA) and chi-squared analysis were used to assess variance between and within groups, where significance was considered as $p < 0.05$.

Results

In the study period, a total of 9,388 trauma patients were admitted. There were 342 deaths in total (4%), of which 185 (54%) occurred within the first 24 h. Of those, 167 had available autopsies (90.3%).

Figure 1 shows the temporal distribution of all trauma deaths, with available autopsies, within 24 h from admission. Of the 167 total deaths, 73 (43.7%), occurred within the first hour. There were 36 (21.5%) deaths in the 1–3 h interval, followed by 17 (10.1%) between 3 and 6 h, 19 (11.3%) deaths between 6 and 12 h, and 22 (13.1%) deaths between 12 and 24 h. The distribution of death over time, as well as mean age, admission blood pressure, base deficit, male gender, mean ISS, and mechanism of injury, is depicted in Table 1. Mean ISS was 41.0 ± 28.7, with a consistent decrease from 43.4 ± 2.4 in the first hour to 31.3 ± 10.6 in the 12–24 hour interval ($p < 0.001$). Similarly, mean systolic blood pressure was 54.2 ± 64.5 mmHg and increased at each interval consistently from a mean of 4.5 mmHg (± 21.6) in the first hour to 150 mmHg (± 48.6) at the 12–24 h interval ($p < 0.001$). The initial mean systolic blood pressure of 4.5 mmHg (± 21.6) in patients dying within the first hour reflects the initial lack of detectable blood pressure in 60 of the 73 patients secondary to severe hypotension. Mean admission base deficit was highest in deaths within the first hour at 15 (± 3.2), but also consistently decreased at each subsequent interval. Mean age of all patients was 44.3 ± 22, with no variance between each time interval ($p = 0.12$). The mechanism of injury was blunt force in 122 (73%) and penetrating in 45 (27%).

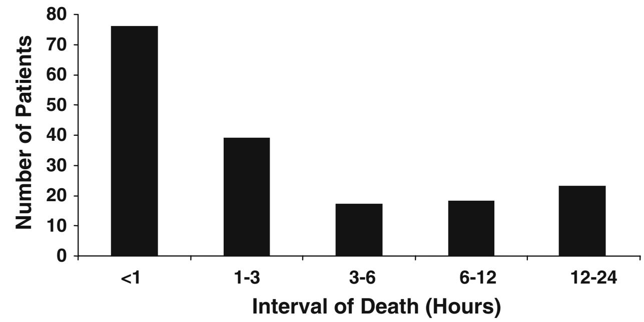

Figure 1. The hourly temporal distribution of early trauma deaths with available autopsies in the first 24 h (n = 167).

Table 2 details a comprehensive list of all injuries as determined by autopsy distributed over each temporal interval. Individual patient injuries were then cross-referenced with the autopsy cause of death. The causes of death were separated into organ systems injured, specifically the categories of brain, thorax, abdominal, peripheral vascular, pelvis or other (Table 3). All causes of death in these categories, except for brain injury, were secondary to hemorrhage and were confirmed by autopsy. Major brain injury, including cerebral contusion, laceration, subdural and subarachnoid hemorrhage, was the most likely cause of death in all groups. In the first hour, thorax injuries represented 34.2% of all deaths, followed by abdomi-

Table 1. Patient death demographics and physiologic characteristics temporally distributed over 24 h (#p = 0.12 between all groups; *p < 0.001 between intervals 0–1 h and 12–24 h; †p < 0.01 between the 0–1 h interval; ^p < 0.001 between all remaining groups; **p < 0.001 between intervals 0–1, 1–3, and 12–24 h).

	0–1 h	1–3 h	3–6 h	6–12 h	12–24 h
Total deaths (n = 167)	73 (43.7%)	36 (21.5%)	17 (10.1%)	19 (11.3%)	22 (13.1%)
Mean age (years)#	42.3 ± 19.9	40.7 ± 20.1	53.2 ± 22.1	51.0 ± 20.2	47.1 ± 21.1
Male gender	59 (80.8%)	29 (80.5%)	14 (82.3%)	16 (84.2%)	19 (86.3%)
Mean ISS	43.4 ± 2.4*	43.5 ± 15.5	42.9 ± 18.7	36.6 ± 12.6	31.3 ± 10.6*
Mechanism of injury: blunt	48 (65.7%)†	27 (75.0%)^	15 (88.2%)^	16 (84.2%)^	16 (72.7%)^
Mechanism of injury: penetrating	25 (34.2%)†	9 (25.0%)^	2 (11.8%)^	3 (15.7%)^	6 (27.2%)^
Mean GCS	3.0 ± 0.4	5.2 ± 3.4	6.9 ± 5.4	6.3 ± 4.7	4.0 ± 1.8
Mean admission SBP (mmHg)**	4.5 ± 21.6	68.4 ± 50.4	103.8 ± 39.5	102.4 ± 54.0	150 ± 48.6
Mean admission base deficit	15 ± 3.2	12 ± 2.1	7.3 ± 1.5	8.9 ± 1.6	3.8 ± 1.8

Table 2. Injuries discovered by autopsy upon early patient death, temporally distributed over 24 h.

	0–1 h	1–3 h	3–6 h	6–12 h	12–24 h
Total deaths (n = 167)	73 (43.7%)	36 (21.5%)	17 (10.1%)	19 (11.3%)	22 (13.1%)
Cerebral contusion/laceration	39	22	15	17	28
Subdural hemorrhage	14	12	7	7	11
Subarachnoid hemorrhage	19	18	13	8	10
Spinal cord	4	5	0	0	0
Cardiac	19	2	0	0	1
Lung	21	7	1	4	0
Aorta	14	2	2	1	0
Vena cava	2	3	1	0	0
Peripheral vascular	9	2	1	1	0
Spleen	16	7	3	5	1
Liver	19	12	1	2	1
Mesentery	4	4	1	2	0
Kidney	6	4	1	3	0
Pelvis	8	6	6	3	1

Table 3. Causes of early patient death, as determined by autopsy, categorized by organ system location and temporally distributed over 24 h.

	0–1 h (%)	1–3 h (%)	3–6 h (%)	6–12 h (%)	12–24 h (%)
Total deaths (n = 167)	73 (43.7)	36 (21.5)	17 (10.1)	19 (11.3)	22 (13.1)
Brain	30 (41.1)	17 (47.2)	10 (58.8)	13 (68.4)	22 (100)
Thorax	25 (34.2)	5 (13.9)	3 (17.6)	1 (5.2)	0
Abdominal	11 (15.1)	12 (33.3)	3 (17.6)	2 (10.4)	0
Peripheral vascular	5 (6.8)	0	0	1 (5.2)	0
Pelvis	0	1 (2.7)	0	1 (5.2)	0
Other	2 (2.7)	1 (2.7)	1 (5.8)	1 (5.2)	0

nal (15.1%) and peripheral vascular (6.8%). In the 1–3 h interval, abdominal injury increased to 33.3% as the cause of death, followed by thorax (13.9%), and pelvis (2.7%). In the 3–6 h interval, both thorax and abdominal injuries represented 17.6% of all deaths. However, when thorax, abdominal, peripheral vascular and pelvis causes of death – all of which represent significant hemorrhage – were combined, they represented 52.1% of all deaths at < 1 h, 50% between 1 and 3 h, and 35.3% between 3 and 6 h. Figure 2 shows the temporal distribution of the cause of death when combining all injuries into the categories of hemorrhage, brain injury and other. All deaths after 12 h were caused by brain injury, and no deaths were

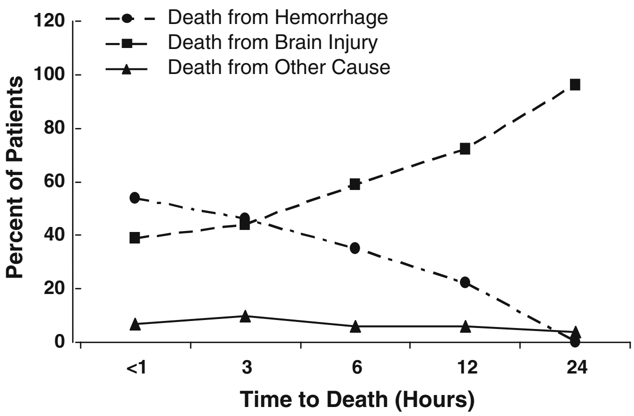

Figure 2. The temporal distribution of autopsy-determined cause of early trauma death, after categorization into brain injury, hemorrhage or other (n = 167).

attributable to hemorrhage in any other category. Causes of death listed under the category ''Other'' included two myocardial infarctions during the 0–1 h interval, two aspirations at the 1–3 and 6–12 h intervals, and one asphyxia at the 3–6 h interval.

Discussion

In 1983 Trunkey et al. [1] provided one of the classic descriptions of trauma epidemiology. Almost half of all traumatic deaths occurred within 1 h after the initiating trauma, giving rise to the ''golden hour'' concept. Trauma deaths occurring within the first hour after injury were from massive hemorrhage or severe brain injury, both of which are deemed mostly unsalvageable [8]. Later deaths, between 1 and 6 h and after one week, formed the trimodal distribution of deaths over time, and has become standard dogma in trauma care and education. Since the inception of the ''golden hour'' concept, pre-hospital care has improved markedly, providing initial resuscitation and decreasing the time of transport to specialized trauma centers. More recently, several authors have shown that the trimodal distribution of trauma mortality has changed significantly, perhaps secondary to the rise of organized trauma systems and overall improvements in trauma care [2, 5]. Similar to Trunkey and Demetriades, nearly half of our deaths (43.7%) occurred within the first hour, and an additional 31.6% occurred within the next six hours [1, 2]. However, since we only analyzed deaths occurring within 24 h, there is some degree of selection bias within these numbers. Furthermore, given the focused time course of this study, we cannot establish whether or not a discernable ''late peak'' after 24 h would occur. In a review of 4,151 trauma deaths, Demetriades et al. [5] showed that death from severe chest trauma occurs mainly within the first hour of injury, followed by a second peak between 1 and 6 h. In our review, chest trauma was the most common cause of death, after brain injury, within the first hour. However, in our analysis, cause of death from abdominal trauma actually peaked between 1 and 3 h and remained high, even at 3–6 h. A further analysis including patients declared dead at the scene may change this finding. Irrespective, death from hemorrhage secondary to abdominal trauma is still an important cause of death as late as 3 h following injury. We also did not find a two-peak distribution of deaths when the cause was brain injury. In our study, death from brain injury continued to increase consistently at each hourly interval. Interestingly, patients who survived beyond 12 h but died before 24 h died exclusively from brain injury.

As reported by Demetriades et al. [2], our temporal distribution of penetrating injury and blunt injury in causing death also differs at each hourly interval. However, the Demetriades group reported a 53.3% incidence of penetrating injury causing death within the first hour. Only after 6 h was the majority of death caused by blunt injury. Our findings show that most deaths in the first hour occur after blunt injury (65.7%). Blunt injury continues to be the most likely etiology causing death at each time interval thereafter. This difference may be explained by the overall lower incidence of penetrating trauma deaths (45) versus blunt trauma deaths (122) in our study.

The development of trauma systems has decreased the incidence of trauma-related death and hospital admissions [9, 10]. With improved transport time and system-wide trauma care, efforts aimed at trying to further decrease mortality within the ''golden hour'' have led several investigators to assess whether patients arriving in extremis may yet be salvageable. In another autopsy-based trauma study reviewing 93 patients, Macleod et al. [11] found that 38% of patients had a single organ injury or isolated vessel which they concluded was a potentially survivable injury. Likewise, Hodgson et al. [6] reviewed autopsy data on 108 blunt injury patients. In their retrospective study, there were high missed injury rates for both abdominal and head trauma, of 43 and 34%, respectively. This is not to suggest that deaths in our study were incorrectly diagnosed or salvageable. Rather, we are suggesting the relative importance of hemorrhage as a cause of death beyond ''the golden hour.'' It is feasible that injuries that previously led to rapid demise within one hour from injury are now physiologically sustained for a longer period of time, given improvements in trauma management over the last three decades. It is widely accepted that implementing rapid ultrasonography and computerized tomography for trauma has decreased the interval from admission to laparotomy [12, 13]. Similarly, early neuroimaging in polytrauma patients continues to play an important role in diagnosing impending neurosurgical emergencies, leading to quicker operative intervention [14]. Whether improving resuscitation, diagnosis or operative intervention may have prevented death from hemorrhage in these patients remains unclear from this data. For instance, abdominal injury, including solid organ and mesenteric injury, accounted for 33% of all deaths between 1 and 3 h; however, the operative or therapeutic measures that prevented patient demise are unknown. These imaging modalities, which are now standard of care, likely play a role in changing the temporal patterns of death from what has been classically described.

Patients that die from trauma within 24 h have a very different cause of death depending on the hour they expire. Those expiring within the first 3 h die mostly from brain injury; however, hemorrhage, and its physiologic consequences, continue to be an important cause of death up to 6 h. Brain injury is the sole cause of death following 12 h. This knowledge may help in the management of severe polytrauma patients. These patients surviving past the ''the golden six'' hours will most likely succumb from brain injury, and management should be directed accordingly. It is important to understand the temporal relationship of death in trauma patients, and an understanding of what causes early death may help in the targeting and management of resources. Patients surviving beyond 6 h are not likely to die from ongoing hemorrhage, and therapy should be targeted as such.

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