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Tri-modal Distribution of Trauma Deaths in a Resource-Limited Setting: Perception Versus Reality

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Abstract

Background Advances in trauma care in high-income countries have significantly reduced late deaths following trauma, challenging the classical trimodal pattern of trauma-associated mortality. While studies from low and middle-income countries have demonstrated that the trimodal pattern is still occurring in many regions, there is a lack of data from sub-Saharan Africa evaluating the temporal epidemiology of trauma deaths.

Methods We conducted a retrospective analysis of the trauma registry at Kamuzu Central Hospital in Lilongwe, Malawi, including all injured patients presenting to the emergency department (ED) from 2009 to 2021. Patients were compared based on timing of death relative to time of injury. We then used a modified Poisson regression model to identify adjusted predictors for early mortality compared to late mortality.

Results Crude mortality of patients presenting to the ED in the study period was 2.4% (n = 4,096/165,324). Most patients experienced a pre-hospital death (n = 2,330, 56.9%), followed by death in the ED (n = 619, 15.1%). Early death (pre-hospital or ED) was associated with transportation by police (RR1.52, 95% CI 1.38, 1.68) or private vehicle (RR1.20, 95% CI 1.07, 1.31), vehicle-related trauma (RR1.10, 95% CI 1.05, 1.14), and penetrating injury (RR1.11, 95% CI 1.04, 1.19). Ambulance transportation was associated with a 40% decrease in the risk of early death.

Conclusions At a busy tertiary trauma center in Malawi, most trauma-associated deaths occur within 48 h of injury, with most in the pre-hospital setting. To improve clinical outcomes for trauma patients in this environment, substantial investment in pre-hospital care is required through first-responder training and EMS infrastructure.

Introduction

Traumatic injury is a leading cause of death and disability, with nearly 6 million fatalities annually. There is a preponderance of injury in low and middle-income countries (LMICs), particularly in sub-Saharan Africa. Furthermore, for every fatal injury, 20–50 non-fatal injuries lead to significant disabilities, reduced workforce productivity, and poor economic development [1, 2].

The concept of "trimodal distribution of trauma deaths," was first described by Trunkey in 1983 [3]. The first and highest death peak included immediate or very early deaths (<60 min), accounting for about 45% of all deaths. Most of these victims had significant traumatic brain or thoracic injuries. The second peak included early deaths (within 1–4 h), accounting for about 34% of deaths. Most of these deaths were a result of severe cardiovascular and intra-abdominal injuries [4]. The third peak included

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late deaths (≥ 1 week) and accounted for about 20% of deaths, most of which resulted from organ failure.

However, many criticize that the concept of trimodal distribution does not represent contemporary general trauma death distribution worldwide. The study included a high penetrating trauma cohort in the United States urban areas in the 1970s. Furthermore, the analysis was performed within a catchment area with an existing trauma system [5]. The advances in trauma care in most high-income countries have significantly reduced late deaths. The evolution of in-hospital trauma care has changed the classical trimodal pattern of deaths following trauma into a bimodal pattern of very early and early deaths [5]. However, limited data from low-income countries showed that the classical trimodal pattern may still be occurring [6]. There is a lack of studies from sub-Saharan Africa that evaluate the temporal epidemiology of trauma deaths.

Like many countries in sub-Saharan Africa, Malawi, a resource-limited country in southeast Africa, has underdeveloped pre-hospital care and regionalized trauma care without a formal trauma system. Therefore, we sought to analyze a large trauma patient population to identify patterns of trauma deaths over time. These data are vital for identifying major gaps in the trauma system in a resource-limited environment.

Methods

This study is a retrospective analysis of the trauma registry from Kamuzu Central Hospital (KCH) in Lilongwe, Malawi. The trauma registry was started in 2008 and prospectively collects data on all trauma patients evaluated at KCH. [7] Patients are recorded in the registry twenty-four hours a day, seven days a week. We record patient and injury characteristics, clinical interventions, and clinical outcomes. Patients are recorded in the trauma registry if they present to KCH with any type of injury.

KCH is a public 1000-bed tertiary care hospital with a catchment area in central Malawi of over eight million people. There is no mature trauma system or pre-hospital transportation system. Most patients are evaluated at a district hospital and then transferred to one of the four tertiary hospitals in Malawi. Transportation to a tertiary hospital is usually via private vehicle or taxi, as ambulances are not widely available. Trauma patients are evaluated by general and orthopedic surgery staff.

We included all injured patients, including burn injury, who presented to the KCH emergency department from January 2009 through December 2021. Our primary aim was to identify patterns of death relative to the time of injury. We initially evaluated the timing of death, treating time as a continuous variable, and present this as a histogram. We then classified patients into the following categories based on a previous analysis of trauma deaths if they were declared dead at KCH: pre-hospital death, death in the emergency department, death less than 48 h, death between 2 and 7 days, and death greater than 7 days [8]. Patients were classified as dying in the pre-hospital setting if they were dead on arrival at the KCH emergency department. In Malawi, patients that die during the pre-hospital period are still brought to the emergency department to be examined and certified dead before being transferred to the morgue.

Initially, we described the distribution of deaths relative to the time to presentation to KCH. We compared patients based on the previously referenced time categories using bivariate analysis. Patients were compared based on demographic data, injury characteristics, and clinical interventions. We also compared the Malawi Trauma Score (MTS), previously described in this environment [9]. For categorical tests, we used Chi-squared tests and one-way analysis of variance for normally distributed continuous variables. For non-normally distributed continuous variables, we used a Kruskal–Wallis test.

We then used a modified Poisson regression model to identify adjusted predictors for trauma-associated early mortality compared to late mortality [10, 11]. Early mortality was defined as death in the pre-hospital setting or the emergency department. We initially fit the model with variables that were statistically significantly different between early and late deaths. We then systemically removed variables that were not significant predictors of early mortality in the model. Risk ratios are reported with a 95% confidence interval.

All statistical analysis was performed using Stata/SE 17.0 (Stata- Corp LP, College Station, TX). The Malawi National Health Services Review Committee and the University of North Carolina Institutional Review Board approved this study.

Results

During the study period, 169,420 injured patients presented to the KCH emergency department. The median age was 24 years (IQR 11–34), and most patients were male (n = 124,701, 73.6%). Crude mortality among all patients was 2.4% (n = 4,096/169, 420). Figure 1 illustrates the density of patient deaths over time with our pre-determined categories labeled. Most patients that died experienced a pre-hospital death (n = 2,330/4,096, 56.9%), while the next most common time period was death in the emergency department (n = 619/4,096, 15.1%). Death in the first 48 h (n = 432/4,906, 10.6%), death between 2 and 7 days

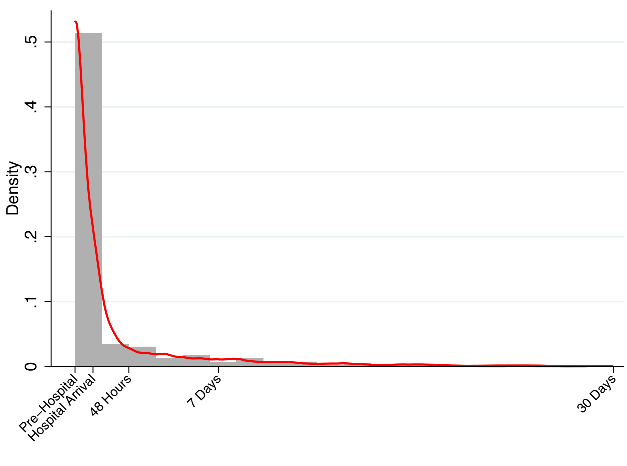

Fig.1 Distribution of trauma-related deaths by time after injury. 139 x 101 mm (600 x 600 DPI)

(*n* = 303/4,906, 7.4%), and death after 7 days (*n* = 412/4,906, 10.1%) all had a similar distribution of patients.

Table 1 compares patient characteristics based on the timing of trauma-associated death. The median age was 30 (IQR 20–38) years in all groups, with men representing at least 70% of patients. However, men comprised a more significant proportion of patients who died earlier at 85.1% of pre-hospital deaths and 70.3% of deaths after 7 days ($p < 0.001$). Vehicle-related injuries were more common in earlier deaths at 48.3% in pre-hospital deaths, 59.6% in ED deaths, and 37.1% in deaths after 7 days ($p < 0.001$). Relatedly, pedestrians struck by motor vehicles more commonly died pre-hospital or in the emergency department. Assaults were also more common among patients who died earlier, while falls were less common. Nearly all patients who died pre-hospital came directly from the scene of their injury (91.3%), but for patients who died in the ED, 35.1% were transferred from another facility. Transferred patients were at least 50% of the other groups. A much higher proportion of patients who died pre-hospital were transported by the police (58%), while police transport was much lower in later deaths at less than 10% ($p < 0.001$). Ambulance use increased significantly for patients who died later. Among pre-hospital deaths, ambulance transportation was only used 7.2% of the time, while it was used more than 50% of the time for patients who died after admission to the hospital ($p < 0.001$).

A comparison of injury characteristics by time of death is shown in Table 2. More than half of patients who died pre-hospital or in the ED had a traumatic brain injury, significantly higher than patients who died later ($p < 0.001$). Patients who died earlier were also more likely to have a penetrating injury at 6.9% and 5.2% in the pre-hospital and ED deaths, respectively ($p < 0.001$), while other groups were at 2.6% or less. Patients who died later were predominantly patients with either burn (41.4%), traumatic brain injury (29.7%), or fractures (15.1%). Median Malawi Trauma Score (MTS) was substantially higher in the pre-hospital death group at 28 (IQR 26–30) and 12 (IQR 9–20) in the ED death group. The median MTS was 9 in each of the other three groups, including late deaths ($p > 0.001$). The proportion of patients who underwent surgery increased over time as more patients had surgery in the later death group, 30.6% compared to just 16.0% for those who died in less than 48 h and 21.5% for those who died between 2 and 7 days ($p < 0.001$).

Using modified Poisson modeling, we identified risk factors for suffering an early death (either pre-hospital or in the emergency department) compared to a later death. Significant factors are shown in Table 3. A vehicle-related injury had a risk ratio (RR) of early death, compared to later, of 1.10 (95% CI 1.05, 1.14). Private vehicle (RR 1.20, 95% CI 1.07, 1.31) and police transportation (RR 1.52, 95% CI 1.38, 1.68) also increased the risk of early death while transportation via ambulance (RR 0.63, 95% CI 0.56, 0.72) protected against early death. A penetrating wound was the only injury type that increased the risk of early death with a RR of 1.11 (95% CI 1.04, 1.19).

Discussion

This study describes the timing of trauma deaths at a tertiary center in Malawi. In contrast to previous reports, we did not identify a trimodal distribution of mortality but rather most deaths occurred within 48 h of injury, with most in the pre-hospital setting. Patients who died in the pre-hospital setting or the emergency department were more likely to be injured by a vehicle-related accident, suffer a penetrating injury, or be transported by the police. Notably, ambulance transportation decreased the risk of an early death.

The distribution of deaths in this study suggests that the risk of dying from traumatic injury drops significantly after a patient is admitted to the hospital. The lack of a late peak in mortality is multifactorial but may reflect the improving quality of trauma care provided at KCH. Over the last 15 years, the number of trauma surgeons has increased, in addition to the availability of operating room and critical care resources such as ventilators. We previously demonstrated that inpatient, tertiary trauma care improved considerably in Malawi after the establishment of a residency training program and educational curriculum. Our 2017 retrospective analysis of trauma patients at KCH showed that the adjusted risk of trauma-associated mortality for inpatients decreased by 50% by the last year of the study [12]. Similarly, mortality associated with traumatic brain injury (TBI) has also improved during this time period due

Table 1 Patient characteristics of patients based on timing of death after traumatic injury

	Pre-Hospital Death (*n* = 2,330)	Died in ED (*n* = 619)	Died < 48 h (*n* = 432)	Died 2–7 days (*n* = 303)	Died > 7 days (*n* = 412)	*P* value
Patient age (years)						
Median (IQR)	30.0 (21.0–36.0)	30.0 (24.0–40.0)	30.0 (12.0–40.0)	30.0 (15.0–45.0)	30.0 (5.0–41.0)	0.003
Gender: N (%)						<0.001
Male	1,960 (85.1)	518 (84.1)	340 (78.9)	229 (75.6)	289 (70.3)	
Female	344 (14.9)	98 (15.9)	91 (21.1)	74 (24.4)	122 (29.7)	
Was injury mechanism vehicle related? N(%)						<0.001
Non-vehicle related	1,158 (51.7)	241 (40.4)	234 (54.7)	166 (55.1)	256 (62.9)	
Vehicle related	1,084 (48.3)	356 (59.6)	194 (45.3)	135 (44.9)	151 (37.1)	
Mechanism of injury: N (%)						<0.001
Pedestrian hit by vehicle	452 (20.2)	141 (23.6)	65 (15.2)	37 (12.3)	53 (13.0)	
Driver/passenger in vehicle accident	632 (28.2)	215 (36.0)	129 (30.1)	98 (32.6)	98 (24.1)	
Fall	49 (2.2)	27 (4.5)	28 (6.5)	24 (8.0)	29 (7.1)	
Assault	547 (24.4)	156 (26.1)	81 (18.9)	39 (13.0)	40 (9.8)	
Collapsed Structure	72 (3.2)	23 (3.9)	16 (3.7)	11 (3.7)	7 (1.7)	
Other	490 (21.9)	35 (5.9)	109 (25.5)	92 (30.6)	180 (44.2)	
Injury setting: N(%)						<0.001
Home	513 (22.9)	108 (17.9)	142 (34.4)	115 (39.0)	193 (47.8)	
Work	43 (1.9)	13 (2.1)	13 (3.1)	10 (3.4)	11 (2.7)	
Street	1325 (59.3)	432 (71.4)	229 (55.4)	161 (54.6)	176 (43.6)	
School	13 (0.6)	4 (0.7)	3 (0.7)	0 (0.0)	2 (0.5)	
Other	342 (15.3)	48 (7.9)	26 (6.3)	9 (3.1)	22 (5.4)	
Transfer: N(%)						<0.001
No	2,105 (91.3)	399 (64.9)	205 (47.8)	112 (37.0)	158 (38.4)	
Yes	200 (8.7)	216 (35.1)	224 (52.2)	191 (63.0)	253 (61.6)	
Transportation mode: N(%)						<0.001
Mini-bus	95 (4.1)	53 (8.7)	43 (10.1)	32 (10.6)	52 (12.7)	
Private Vehicle	639 (27.9)	218 (35.6)	125 (29.3)	74 (24.6)	106 (25.9)	
Ambulance	165 (7.2)	192 (31.4)	215 (50.4)	177 (58.8)	229 (56.0)	
Police	1331 (58.0)	133 (21.7)	38 (8.9)	15 (5.0)	16 (3.9)	
Walked	0 (0.0)	3 (0.5)	1 (0.2)	0 (0.0)	4 (1.0)	
Other	63 (2.7)	13 (2.1)	5 (1.2)	3 (1.0)	2 (0.5)	

to enhancements in critical care and head injury management [13]. The relative risk of dying from a TBI decreased by 30% from 2013 to 2017. While there is room for continued improvement, investment in health professionals and hospital infrastructure has led to improved clinical outcomes for trauma patients. It is also possible that fewer late deaths are explained by a shift toward pre-hospital deaths in this environment, biasing our results toward patients who were able to survive the early period after injury. Later deaths were dominated by patients with TBI or burns, demonstrating the challenge of managing potential long-term complications from patients with these specific injury types.

Predictors of early death included vehicle-related trauma and penetrating wounds. These findings signal the relative severity of these injuries compared to other mechanisms, such as falls or blunt assaults. As the country has grown economically over the last 20 years, the use of motor vehicles has increased rapidly. Concomitantly, there has been a substantial increase in road traffic collisions and their associated traumatic injuries [14, 15]. Unfortunately, a virtually non-existent pre-hospital care system puts these patients at greater risk of poor outcomes. This is also true

Table 2 Injury characteristics of patients based on timing of death after traumatic injury

	Pre-hospital death (*n* = 2,330)	Died in ED (*n* = 619)	Died < 48 h (*n* = 432)	Died 2–7 days (*n* = 303)	Died > 7 days (*n* = 412)	*P* value
Most severe injury type: N(%)						<0.001
Soft Tissue Injury	231 (10.1)	78 (12.7)	45 (10.4)	22 (7.3)	34 (8.3)	
Fracture	167 (7.3)	68 (11.1)	55 (12.8)	32 (10.6)	62 (15.1)	
Dislocation	2 (0.1)	1 (0.2)	1 (0.2)	1 (0.3)	2 (0.5)	
Traumatic Brain Injury	1,200 (52.5)	367 (59.7)	176 (40.8)	147 (48.5)	122 (29.7)	
Penetrating Wound	158 (6.9)	32 (5.2)	11 (2.6)	2 (0.7)	8 (1.9)	
Burn	94 (4.1)	20 (3.3)	102 (23.7)	86 (28.4)	169 (41.1)	
Other	432 (18.9)	49 (8.0)	41 (9.5)	13 (4.3)	14 (3.4)	
Most severe injury location: N(%)						<0.001
Head or Face	1,407 (66.6)	437 (71.5)	241 (56.2)	175 (57.8)	178 (43.5)	
Spine	219 (10.4)	16 (2.6)	26 (6.1)	23 (7.6)	31 (7.6)	
Chest	114 (5.4)	30 (4.9)	14 (3.3)	19 (6.3)	17 (4.2)	
Abdomen/Flank	153 (7.2)	45 (7.4)	63 (14.7)	30 (9.9)	55 (13.4)	
Upper Extremity	51 (2.4)	19 (3.1)	15 (3.5)	15 (5.0)	27 (6.6)	
Hand	27 (1.3)	9 (1.5)	15 (3.5)	10 (3.3)	24 (5.9)	
Pelvis	22 (1.0)	7 (1.1)	13 (3.0)	3 (1.0)	19 (4.6)	
Lower Extremity	119 (5.6)	48 (7.9)	42 (9.8)	28 (9.2)	58 (14.2)	
Malawi trauma score: median (IQR)	28.0 (26.0–30.0)	12.0 (9.0–20.0)	9.0 (9.0–12.0)	9.0 (8.0–10.0)	9.0 (8.0–12.0)	<0.001
Underwent surgery? N(%)						
No	2,330 (100.0)	619 (100.0)	363 (84.0)	238 (78.5)	286 (69.4)	<0.001
Yes	0 (0.0)	0 (0.0)	69 (16.0)	65 (21.5)	126 (30.6)	

Table 3 Adjusted predictors of an early death (pre-hospital or in the emergency department) versus late death after traumatic injury for patients presenting to Kamuzu Central Hospital

Patient factor	Adjusted RR of early death (95% CI)	*p* value
Vehicle related injury	1.10 (1.05, 1.14)	< 0.001
Transportation mode		
Private vehicle	1.20 (1.07, 1.31)	0.001
Ambulance	0.63 (0.56, 0.72)	<0.001
Police	1.52 (1.38, 1.68)	<0.001
Walked	0.66 (0.29, 1.52)	0.3
Other	1.36 (1.20, 1.53)	<0.001
Injury type		
Fracture	0.84 (0.77, 0.92)	<0.001
Dislocation	0.69 (0.30, 1.61)	0.4
Head injury	1.05 (0.99, 1.22)	0.1
Penetrating wound	1.11 (1.04, 1.19)	0.002
Burn	0.44 (0.37, 0.52)	<0.001
Other	1.15 (1.08, 1.22)	<0.001

for penetrating injuries, which, while not common in Malawi, are often fatal, with early deaths prevalent [16].

So, while inpatient trauma management has improved, this study illustrates the continued importance of pre-hospital care. The overwhelming majority of patients died either prior to arrival at the emergency department or shortly after arrival, with very few patients transported in an ambulance. Consistent with a previous report from Malawi, transportation to the hospital by the police was the most predictive factor of an early death, increasing the risk by nearly 50% [17]. The role of police in transporting injured patients from the scene has been controversial in the United States, with conflicting evidence about the safety and timeliness of transfer [18–20]. Data from neighboring countries in sub-Saharan Africa have been mixed, with some reports showing no adverse outcomes related to police transport [21, 22]. However, evidence from Malawi showed that police transfer to the hospital after a motor vehicle injury increased the adjusted risk of death by 50% compared to private vehicle transportation [23].

In environments with limited pre-hospital care availability, the police or private vehicles will inevitably transport patients to the hospital, especially after motor vehicle collisions or assaults. Consequently, there has been considerable research into using bystanders as providers of basic first aid and transportation to medical facilities. A 2018 systematic review showed that bystander training was vital given the lack of pre-hospital resources in most LMICs [24]. Data from neighboring Tanzania showed that first aid knowledge of police was very poor despite two-thirds reporting previous training [25]. This suggests that more thorough and intensive training of police and other potential laypersons is needed. A 2009 feasibility study from Uganda showed that a training program targeting police, taxi drivers, and other laypersons with focused education improved first aid significantly [26]. A similar program in Mozambique also showed promise [27]. These programs likely have high public health value and should be considered in environments with limited pre-hospital care. Not surprisingly, transportation via ambulance was protective against early death, despite Malawi's underdeveloped emergency medical services (EMS) system. The challenges of building pre-hospital infrastructure in resource-limited environments have been well documented [28]. However, as trauma systems mature in these settings, investment in an EMS system will be vital to ensuring that patients can be safely transported [29].

This study is limited by our inability to identify the exact cause of death for trauma patients. However, because most patients are transported to the emergency department, even after a fatal injury, we can capture data on patient and trauma characteristics, even for patients who died in the pre-hospital setting. We are also missing initial vital signs for patients who died in the pre-hospital setting, as these are not recorded or available for this patient population. We have attempted to stratify patients based on demographics and injury characteristics.

Conclusion

At a busy tertiary trauma center in Malawi, most trauma-associated deaths occur within 48 h of injury, with most in the pre-hospital setting. Patients who died early were more likely to be injured by a vehicle-related accident, suffer a penetrating injury, or be transported by the police or private vehicle. In contrast, ambulance transportation decreased the risk of early death by nearly 40%. To improve clinical outcomes for trauma patients in this environment, substantial investment in pre-hospital care is required through first-responder training and EMS infrastructure.

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