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Potentially preventable trauma deaths: A retrospective review

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ABSTRACT

Background: Reviewing prehospital trauma deaths provides an opportunity to identify system improvements that may reduce trauma mortality. The objective of this study was to identify the number and rate of potentially preventable trauma deaths through expert panel reviews of prehospital and early in-hospital trauma deaths.

Methods: We conducted a retrospective review of prehospital and early in-hospital (<24 h) trauma deaths following a traumatic out-of-hospital cardiac arrest that were attended by Ambulance Victoria (AV) in the state of Victoria, Australia, between 2008 and 2014. Expert panels were used to review cases that had resuscitation attempted by paramedics and underwent a full autopsy. Patients with a mechanism of hanging, drowning or those with anatomical injuries deemed to be unsurvivable were excluded.

Results: Of the 1183 cases that underwent full autopsies, resuscitation was attempted by paramedics in 336 (28%) cases. Of these, 113 cases (34%) were deemed to have potentially survivable injuries and underwent expert panel review. There were 90 (80%) deaths that were not preventable, 19 (17%) potentially preventable deaths and 4 (3%) preventable deaths. Potentially preventable or preventable deaths represented 20% of those cases that underwent review and 7% of cases that had attempted resuscitation.

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Conclusions: The number of potentially preventable or preventable trauma deaths in the pre-hospital and early in-hospital resuscitation phase was low. Specific circumstances were identified in which the trauma system could be further improved.

Introduction

Regionalised trauma systems aim to ensure that severely injured patients are transported to trauma centres with appropriate specialist staff and equipment in a timely fashion, with the objective of reducing preventable deaths and disability. These systems have been demonstrated to reduce trauma mortality and morbidity globally. [1–4]

Reviewing preventable trauma deaths, a method first used in the 1970s, has been a mechanism used to examine quality of care, outcomes and evaluate the implementation of trauma systems [5–7]. In Victoria, Australia, the work of the Consultative Committee of Road Traffic Fatalities, led by McDermott et al. [8] was instrumental in the introduction of the Victorian State Trauma System; a regionalised trauma system that has been demonstrated to significantly improve outcomes for major trauma patients [1,2].

The majority of trauma deaths occur in the prehospital setting [9,10]. Yet, these deaths have not been subject to the same scrutiny as in-hospital deaths. Reviewing prehospital trauma deaths provides an opportunity to examine the entire system of care provided to trauma patients, not limited to those that survive to hospital, as is common in many reviews of trauma deaths [11,12]. Reviews of prehospital deaths can inform the optimisation of the system of care provided to trauma patients, including improvements to prehospital coordination, clinical care, and the role of novel technologies and clinical interventions [13].

The use of multidisciplinary expert panel reviews is considered the most robust approach to reviewing potentially preventable trauma deaths [14,15]. Despite this, contemporary expert panel reviews of prehospital trauma deaths are rare. Studies from Kleber et al. in Berlin [16] and Girard et al. in northern France [17] are the exceptions. However, given that Australian data on preventable deaths is more than a decade old [8,18,19], there is a need to provide new evidence on whether a proportion of trauma deaths could have been prevented and what system improvements should be implemented to reduce trauma mortality. Therefore, the primary aim of this study was to identify the number and rate of preventable and potentially preventable trauma deaths and determine the components of current clinical pathways where best evidence care was not delivered. A secondary aim was to identify opportunities to improve the system of care provided to severely injured trauma patients.

Methods

Study design

We performed a retrospective review of prehospital trauma deaths and early in-hospital (<24 h) trauma deaths following a traumatic out-of-hospital cardiac arrest (OHCA) that were attended by Ambulance Victoria (AV) between 2008 and 2014. Patients with a mechanism of hanging or drowning were excluded. The study protocol has been published previously [20] and additional methodological details are provided in the Supplementary Material.

Setting

The study was conducted in the State of Victoria, Australia (population of 5.6 million people). AV is the sole provider of emergency medical service (EMS) in the state. AV deliver a three-tiered EMS system, with Advanced Life Support Paramedics (ALS), Intensive Care Paramedics (ICP) and first responders with basic life support (BLS) skills who respond in select areas of Victoria.

Data sources

Prehospital and early in-hospital (<24 h) trauma deaths were identified using the Victorian Ambulance Cardiac Arrest Registry (VACAR), a population-based registry of all OHCA events attended by AV [21]. All deaths attended by paramedics are collected in VACAR and all deaths are considered to have had an OHCA. These data were linked with coronial data (including the autopsy report, police report and forensic toxicology report) from the National Coronial Information System [20]. For patients that survived to hospital, data were linked with the Victorian State Trauma Registry [22].

Inclusion criteria

Cases were included for detailed review if they were successfully linked, had attempted resuscitation by paramedics, underwent a full autopsy and the autopsy was electronically available. Criteria for withholding or ceasing resuscitation attempts have previously been described [9]. In short, paramedics can withhold resuscitation when there is clear evidence of prolonged cardiac arrest or when injuries are incompatible with life.

Review process

A two phase review process was used [20].

Phase 1: survivability assessment

Included cases underwent a detailed clinical review to determine whether the anatomical injuries were ‘survivable’; that is, cases in which the anatomical injuries were potentially survivable in ideal situations, but the patient died (Supplementary Material). [20]

Phase 2: expert panel reviews

In cases that were deemed to be ‘survivable’, multidisciplinary panels were used to identify components of the system of care where current best evidence care was not delivered. Four sub-panels were utilised to review these cases and comprised at least the following:

- 1 intensive care paramedic
- 1 emergency physician or trauma surgeon
- 1 other (e.g. ALS paramedic, nurse, forensic pathologist, injury epidemiologist)

The review was conducted under the framework of the clinical practice that was relevant at the time of the death. Two weeks prior to the review, panellists were provided with the prehospital patient care records for each of the attending ambulance crews (and in-hospital records, where appropriate), the police report, toxicology data and the full autopsy. Specific areas for improvement were identified a priori (Supplementary Material) [20]. More than one area for improvement could be assigned to each case.

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Preventability assessment

Preventability was classified using classifications from the World Health Organization's (WHO) Guidelines for Trauma Quality Improvement Programs [23], Shackford et al. [24] McKenzie et al. [25] Vioque et al. [26] and Oliver & Walter [27] as a guide, as follows:

- *Not preventable*
  - System provided appropriate and timely care
  - Evaluation and management was appropriate according to relevant clinical guidelines
- *Potentially preventable*
  - System generally provided appropriate and timely care, although potential for improvement
  - Evaluation and management generally appropriate
  - Some deviations from standard of care that may, directly or indirectly, have been implicated in the patient's death
- *Preventable*
  - Delivery of care was suboptimal
  - Avoidable error is judged to have directly caused the final outcome

Where 100% agreement on preventability could not be achieved during the expert panel reviews, cases were taken to a wider panel review. This wider panel review included three intensive care paramedics, five emergency physicians / trauma surgeons and one forensic pathologist.

Novel interventions

In addition to reviewing trauma deaths with respect to clinical practice that was relevant at the time of the death, expert panellists were also asked to consider the role of interventions that were or are novel in the context of prehospital care in the Victorian State Trauma System. A list of interventions were defined a priori by a team of highly-experienced prehospital and in-hospital trauma clinicians (Supplementary Material). More than one intervention could be assigned to each death.

Analysis

All injuries were coded using the Abbreviated Injury Scale (AIS) 2005 (2008 update) [28] and the Injury Severity Score (ISS) calculated. Coding was conducted by clinical coders who were accredited in AIS coding.

To assess the reliability of preventability between panels, 20 cases were randomly allocated to be independently reviewed by two panels. Comparisons between groups were made using the Wilcoxon rank-sum test for non-normally distributed continuous variables and the chi-square test or Fisher's exact test for categorical variables. Data analysis was performed using Stata (Version 14.2, StataCorp, College Station, TX). A p-value <0.05 was considered statistically significant.

Ethics committee approval

The present study was approved by the Victorian Department of Justice and Regulation Human Research Ethics Committee (HREC) (CF/16/272) and the Monash University HREC (CF16/532 – 2016000259).

Results

Over the 7 year study period, there were 2752 prehospital and early in-hospital deaths following traumatic OHCA. Of these, 2612 (95%) were successfully linked to NCIS data. Of the linked cases, 1429 (55%) were excluded due to having external-only examinations (n = 1156; 44%) or unavailable autopsy results (n = 273; 11%). Differences in the age, sex, intent, location and mechanism of injury were observed between deaths with a full autopsy and deaths with an external-only examination or where the autopsy result was not available (Supplementary Material). Of the 1183 (45%) cases that had full autopsies, resuscitation was attempted in 336 (28%) cases (Fig. 1).

Following detailed review of the autopsy results, 223 (66%) were excluded from the expert panel reviews due to having either unsurvivable anatomical injuries (n = 187; 56%), being a primary medical event (n = 31; 9%) or the prehospital patient care record being unavailable (n = 5; 1%). Thus, 113 cases (34%) were deemed to have potentially survivable anatomical injuries and underwent expert panel review (Fig. 1). Comparisons between cases that underwent review and cases excluded are presented in Table 1.

Potentially preventable or preventable deaths

Of the 113 cases that underwent expert panel review, consensus was reached by the sub-panels in 111 cases (98%). Two cases were taken to wider-panel review where a final decision was reached. Of the 113 cases, there were 90 (80%) not preventable deaths, 19 (17%) potentially preventable deaths and 4 (3%) preventable deaths (Table 2). Potentially preventable or preventable deaths represented 20% of those cases that had potentially survivable anatomical injuries (23 of 113) and 7% of cases that had attempted resuscitation from paramedics (23 of 336). The proportion of cases that were potentially preventable or preventable deaths was similar between blunt and penetrating trauma, but were higher in metropolitan regions compared to rural regions (Table 2). The median ISS was lower in preventable deaths relative to potentially preventable or not preventable deaths (Table 2).

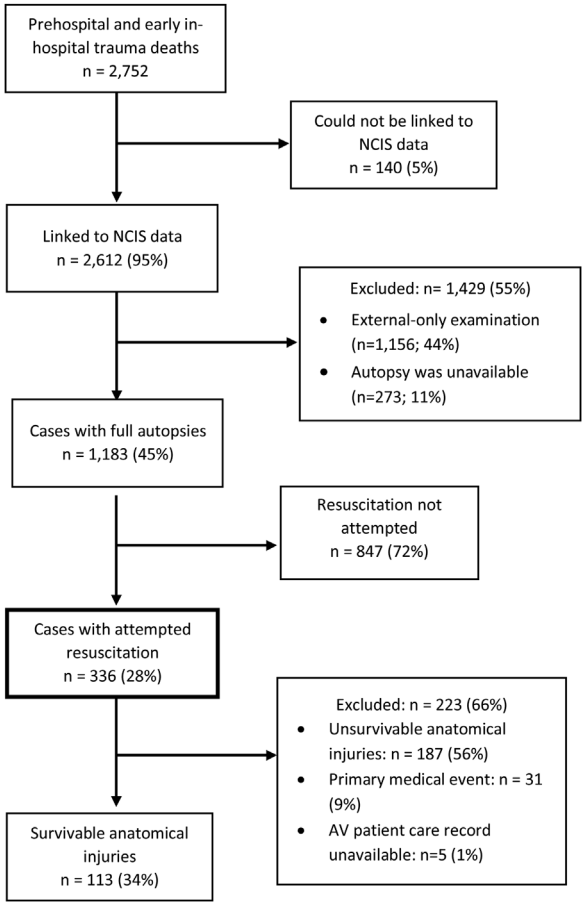

Fig. 1. Patient selection.

Table 1
Comparisons between cases that underwent review and those cases that were excluded. Cases that did not have attempted resuscitation from paramedics or did not undergo a full autopsy were excluded from these comparisons.

	Cases that underwent review	Cases excluded	p-value
N	113	223	
Age (years); median (IQR)	46.0 (32.0, 63.0)	40.0 (25.0, 60.0)	0.047
Sex			0.44
Male	85 (75.2%)	176 (78.9%)	
Female	28 (24.8%)	47 (21.1%)	
Intent			0.044
Unintentional	83 (74.1%)	147 (73.5%)	
Intentional Self-Harm	3 (2.7%)	17 (8.5%)	
Assault	23 (20.5%)	25 (12.5%)	
Other	3 (2.7%)	11 (5.5%)	
Location			0.70
Highway, Freeway, Street or Road	60 (53.1%)	136 (61.0%)	
Home	28 (24.8%)	46 (20.6%)	
Farm	6 (5.3%)	8 (3.6%)	
Industrial Or Construction Area	4 (3.5%)	8 (3.6%)	
Other	15 (13.3%)	25 (11.2%)	
Trauma type			0.014
Blunt	82 (73.2%)	163 (80.7%)	
Penetrating	24 (21.4%)	31 (15.3%)	
Thermal Mechanism	2 (1.8%)	3 (1.5%)	
Threat To Breathing	4 (3.6%)	0 (0.0%)	
Other	0 (0.0%)	5 (2.5%)	
Mechanism of injury			0.045
Transport Injury Event	64 (57.1%)	127 (62.9%)	
Fall (any)	5 (4.5%)	20 (9.9%)	
Crushing/ Threat to Breathing	11 (9.8%)	5 (2.5%)	
Contact with Person	4 (3.6%)	4 (2.0%)	
Penetrating: stabbing	16 (14.3%)	21 (10.4%)	
Penetrating: shot by firearm	5 (4.5%)	9 (4.5%)	
Penetrating: scratching, cutting	2 (1.8%)	1 (0.5%)	
Thermal Mechanism	2 (1.8%)	3 (1.5%)	
Other	3 (2.7%)	12 (5.9%)	
Injury Severity Score; median (IQR)	27 (19, 41)	38 (25, 75)	<0.001

Missing data: intent - n=24 (7%); mechanism of injury - n=22 (7%).

Table 2
Comparisons of preventability groups.

	Potentially preventable	Preventable	Not preventable
N	19	4	90
Age, years			
0–15	1 (5%)	1 (25%)	1 (1%)
16–34	4 (21%)	1 (25%)	25 (28%)
35–64	8 (42%)	1 (25%)	45 (50%)
65 plus	6 (32%)	1 (25%)	19 (21%)
Trauma type			
Blunt	14 (74%)	3 (75%)	65 (73%)
Penetrating	5 (26%)	1 (25%)	18 (20%)
Other	0 (0%)	0 (0%)	6 (7%)
Region			
Metropolitan	14 (74%)	1 (25%)	43 (48%)
Rural	5 (26%)	3 (75%)	47 (52%)
Injury Severity Score; median (IQR)	27 (22, 41)	14 (10, 20)	29 (19, 41)

Missing data: trauma type - n=1 (1%).

Inter-panel reliability

Twenty cases were independently reviewed by two panels with agreement achieved in 19 of 20 cases.

Areas for improvement

Potentially preventable or preventable deaths

Among all potentially preventable or preventable deaths, eight cases were identified to have areas for improvement in the response of the system: four cases had long response times and four cases had potential issues related to dispatch or recognition in the emergency call (Table 3). In the latter four cases, the traumatic cardiac arrest or severity of injuries was not recognised in the initial call, and the case was determined to have been under-triaged. There were six cases where areas for improvement in diagnosis by paramedics were identified, which were a combination of delayed recognition of trauma and severity of injury.

There were five cases in which the on-scene time was noted to be excessive. In all five cases, these were haemorrhaging patients where it was deemed immediate transport to definitive care for surgical management was the highest priority. There were four cases in which the injury was inappropriately deemed unsalvageable at scene resulting in resuscitation efforts being ceased prematurely.

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Table 3
Areas for improvement identified in the expert panel reviews, with results stratified by preventability groups.

N	Potentially preventable 19	Preventable 4	Not preventable 90
System factors			
Long notification time (time from injury event to 000 call)	1	0	0
Long response time	2	2	5
Dispatch / recognition in the call	4	0	0
Other	1	0	3
Diagnostic factors			
Missed/incorrect diagnosis	6	0	1
Delayed diagnosis	0	0	0
Other	0	0	0
Treatment/management factors			
Delayed treatment	1	0	1
Incorrect procedure	1	0	0
Correct procedure, but with complication	2	0	1
Correct procedure, incorrectly performed	2	0	1
Procedure not performed	3	3	4
Equipment failure	0	0	0
Inaccurate prognosis	4	0	2
Excessive on-scene time	4	1	0
Triage error	2	0	1
Other	5	0	1

There were 20 cases where potential areas for improvement in the management of the patient were identified (Table 3). There were two cases in which the correct procedure was performed, but resulted in a complication, both of which related to ineffective needle pleural decompression with tension pneumothoraces observed on post-mortem. There were six cases in which it was deemed that a necessary procedure was not performed. In three of four preventable deaths, an absence of appropriate haemorrhage control was noted.

Not preventable deaths

Potential areas for improvement in the 90 cases where the deaths were deemed to be not preventable are summarised in Table 3. There were five cases that identified areas for improvement in the response of the system. All of these cases related to long response times; one of which one related to the incorrect provision of the scene address and one case in which there was a delay in activating helicopter emergency medical services (HEMS). There was one case that had areas for improvement in diagnosis. Specifically, a significant pelvic fracture was missed. Nine cases had areas for improvement in the management of the patient. Three cases had a necessary procedure that was not performed, including chest decompression, and pelvic and lower limb splinting. There were no cases in which the on-scene time was noted to be excessive. There were two cases in which early prognostication resulted in resuscitation efforts being ceased prematurely.

Novel interventions

Sixty-seven of the 113 (59%) cases that underwent review had novel interventions noted that may have improved outcomes. These interventions were or are novel in the context of prehospital care in the Victoria State Trauma System and are detailed in Table 4.

Table 4
Noted novel system-related and clinical interventions that may have improved outcomes. These were documented for all cases that underwent review (n = 113).

System-related interventions	Number of cases identified where novel intervention may have improved outcome
Early notification system (e.g. automatic crash notification or automatic quad-bike rollover notification)	4
Video emergency call	8
Provision of GPS coordinates as part of emergency call	2
Improved protocol around trapped patients	5
Improved protocol for crushed patients	2
Rapid launch protocol for HEMS	3
Clinical interventions	
Prehospital point of care ultrasonography	17
Prehospital resuscitative endovascular balloon occlusion of the aorta (REBOA)	2
Prehospital thoracotomy	0
Prehospital blood products (red cell concentrate / packed red bloods cells) [a]	24
Finger thoracostomy [b]	17
Arterial tourniquets	4
Novel methods of haemorrhage control (abdominal packing)	2
Remote decision-making support (telemedicine) for paramedics	6
Query the benefit of intubating a haemorrhagic/shocked patient, particularly in cases of penetrating chest trauma	6
Provide SAM pelvic binder to all crews [c]	6
Prioritise short on-scene times, particularly in penetrating trauma	5
Increased education on impact brain apnoea	2

Note: a) Intensive care flight paramedics have been able to administer blood products since 2011; b) currently in use by intensive care flight paramedics; c) this has already been addressed by Ambulance Victoria.

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Discussion

In this detailed review of prehospital and early in-hospital trauma deaths following traumatic OHCA over a 7-year period, there were 23 cases identified that were potentially preventable or preventable. In a small number of patients, systems of care provided to the patient were considered suboptimal. The identification of these areas for improvement provide opportunities to make incremental improvements that may reduce trauma mortality.

Our observed rate of potentially preventable or preventable deaths is lower than that previously reported. Excluding patients who died prior to the arrival of prehospital emergency physicians, Girard et al. [17] reported 21% of trauma deaths were considered potentially preventable or preventable in a region of northern France. Kleber et al. reported 15% of all trauma deaths (excluding deaths from strangulation, burns or drowning) were considered potentially preventable or preventable in Berlin, Germany. In our setting of Victoria, Australia, McDermott et al. previously noted that 67% of road traffic fatalities had errors that contributed to death [8]. This rate significantly declined after the introduction of the Victorian State Trauma System [29] and this was reflected in reductions in risk-adjusted in-hospital mortality [1]. The potentially preventable or preventable death rate in our study was substantially lower, demonstrating the effectiveness of our mature trauma system and the provision of high-quality prehospital care.

We identified only a small number of specific circumstances in which the system of care provided to the patient was suboptimal. Preventable deaths studies are limited to focussing on only patients that die and therefore miss opportunities to identify situations in which system or clinical components have been effective. In the setting of a low rate of potentially preventable or preventable deaths, any suggested changes to trauma systems are made with the caveat of requiring further evaluation. None the less, our study highlights potential opportunities to make incremental improvements to trauma care.

Twenty of 23 potentially preventable or preventable deaths had areas for improvement in the management of the patient. In our region, paramedics are typically exposed to traumatic OHCA once every 9.5 years [30], and continued efforts to ensure that paramedics maintain resuscitation skills and adhere to current clinical practice guidelines are warranted. This may include the use of telemedicine and other forms of remote decision support, particularly in remote places or where paramedics request clinical support [31].

In three of four preventable deaths, an absence of adequate haemorrhage control was noted. Haemorrhage has previously been identified as a leading cause of preventable deaths [16] and in these cases, control of major haemorrhage is the main priority. External haemorrhage can be managed through the use of tourniquets and/or topical haemostatic agents [32], both of which are now routine clinical practice in Ambulance Victoria. In patients with ongoing haemorrhage, time to definitive treatment at hospital is critical. It was noted that five potentially preventable or preventable deaths had excessive on-scene times; these were all in the setting of significant haemorrhage. Minimising on-scene times in these haemodynamically unstable patients, particularly in penetrating trauma, is critical to reducing mortality [33,34].

Ineffective chest decompression was noted in two cases. Anterior needle thoracocentesis has been noted to be an unreliable means of decompressing the chest of an unstable patient and it has been recommended that blunt dissection and digital decompression through the pleura (finger thoracostomy) is used [35,36]. Within our system, prehospital finger thoracostomy has been performed by intensive care flight paramedics since 2016, but this procedure is not currently endorsed for use by road-based paramedics.

There were a number of system and clinical interventions that were or are novel in the context of prehospital care in our trauma system. Novel system-related interventions that were identified included early notification systems, video emergency calls, the provision of GPS coordinates as part of the emergency call, and improved protocols around trapped or crushed patients. Automatic crash notification systems automatically contact EMS with the aim of reducing EMS response times and reducing mortality [37]. Such a system (eCall) has now been introduced in all new vehicles sold in Europe from April 2018. Additionally, providing the GPS coordinates from mobile phones as part of the emergency call would address situations where the incorrect address is provided in the call. We also identified a number of situations in which a video link from the scene to the emergency call centre may have provided a greater level of information about the scene (for example, the severity of entrapment in a vehicle) and the ability to provide first-aid instructions to bystanders.

The timeliness of the dispatch of HEMS was queried in three cases. Tasking dispatch of HEMS or critical care units by clinicians with experience in prehospital critical care has been shown to improve the identification of severely injured trauma patients and reduce response times [38,39]. Therefore, in our region, consideration should be given to upgrading the qualification of the HEMS flight coordinator from an ALS paramedic to a senior intensive care paramedic.

A number of clinical interventions were suggested during expert panel reviews for application in our trauma system, including the use of prehospital point of care ultrasonography and the administration of blood products (currently limited to intensive care flight paramedics). Military data on the use of prehospital blood products has demonstrated a greater likelihood of survival [40], however civilian data are limited, and we await the results of current randomised controlled trials [41].

There has been growing international interest in taking invasive interventions used in the in-hospital setting to the prehospital setting, such as thoracotomy and resuscitative endovascular balloon occlusion of the aorta (REBOA). Previous studies are limited to very small numbers [42–44], and our results reflect this with panels suggesting that only two cases may have benefited from REBOA and no cases may have benefited from prehospital thoracotomy. Thus, the establishment of a system to provide REBOA or thoracotomies in our prehospital setting cannot be justified based on improvements in mortality.

The strengths of this study include the highly detailed review of trauma deaths using multi-disciplinary expert panels. Expert panel reviews of trauma deaths have been criticised for poor inter-panel reliability [14]. However, using a robust and internationally-recognised review methodology [20], we demonstrated a high level of agreement between panels. Furthermore, we have developed a methodology that is sustainable and reproducible over time and will enable robust comparisons between jurisdictions. This methodology focusses on prioritising the review of cases that had the potential for survival and is therefore an effective and efficient approach to identifying improvements to trauma systems. However, this study is not without limitations. Only half of the trauma deaths in this study had a full autopsy. Amid declining autopsy rates [45], increasing utilisation of post-mortem computed tomography may be needed. In this study, preventability was assessed based on clinical practice that was relevant at the time of the death, which is a strength of the study. However, this limits the ability to quantify cases in which changes to the system or clinical care may have led to improved outcomes. Furthermore, excluding cases in whom resuscitation was not attempted may under-represent the true number of preventable deaths, such as in situations where withholding resuscitation may have been a clinical error. Excluding trauma deaths that were not

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attended by EMS may also under-represent the true number of preventable deaths. Additionally, the majority of deaths in this study had unsurvivable anatomical injuries and there may be greater opportunities to understand ways to reduce trauma mortality by investigating early in-hospital deaths.

Conclusion

Using an in-depth expert panel review methodology, we identified a low rate of potentially preventable or preventable trauma deaths in a mature trauma system. We identified some specific circumstances in which the system of care could be further improved through novel system and clinical interventions. The potential incremental benefit from such interventions requires further evaluation. It is recommended that trauma systems consider utilising a similar methodology to ensure rigorous and efficient reviews of trauma deaths with the aim of improving systems of care.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.injury.2019.03.003.

References

[1] Cameron PA, Gabbe BJ, Cooper DJ, Walker T, Judson R, McNeil J. A statewide system of trauma care in Victoria: effect on patient survival. Med J Aust 2008;189(10):546–50.
[2] Gabbe BJ, Simpson PM, Sutherland AM, et al. Improved functional outcomes for major trauma patients in a regionalized, inclusive trauma system. Ann Surg 2012;255(6):1009–15.
[3] MacKenzie EJ, Rivara FP, Jurkovich GJ, et al. A national evaluation of the effect of trauma-center care on mortality. N Engl J Med 2006;354(4):366–78.
[4] Nathens AB, Jurkovich GJ, Cummings P, Rivara FP, Maier RV. The effect of organized systems of trauma care on motor vehicle crash mortality. JAMA 2000;283(15):1990–4.
[5] Detmer DE, Moylan JA, Rose J, Schulz R, Wallace R, Daly R. Regional categorization and quality of care in major trauma. J Trauma 1977;17(8):592–9.
[6] Moylan JA, Detmer DE, Rose J, Schulz R. Evaluation of the quality of hospital care for major trauma. J Trauma Inj Infect Crit Care 1976;16(7):517–23.
[7] West JG, Cales RH, Gazzaniga AB. Impact of regionalization: the Orange County experience. Arch Surg 1983;118(6):740–4.
[8] McDermott FT, Cooper GJ, Hogan PL, Cordner SM, Tremayne AB. Evaluation of the prehospital management of road traffic fatalities in Victoria, Australia. Prehosp Disaster Med 2005;20(04):219–27.
[9] Beck B, Bray JE, Cameron P, et al. Resuscitation attempts and duration in traumatic out-of-hospital cardiac arrest. Resuscitation 2017;111:14–21.
[10] Morrison JJ, Yapp LZ, Beattie A, et al. The epidemiology of Scottish trauma: a comparison of pre-hospital and in-hospital deaths, 2000 to 2011. Surgeon 2016;1(14):1–6.
[11] Gruen RL, Jurkovich GJ, McIntyre LK, Foy HM, Maier RV. Patterns of errors contributing to trauma mortality: lessons learned from 2594 deaths. Ann Surg 2006;244(3):371.
[12] Teixeira PG, Inaba K, Hadjizacharia P, et al. Preventable or potentially preventable mortality at a mature trauma center. J Trauma Acute Care Surg 2007;63(6):1338–47.
[13] Beck B, Smith K, Mercier E, Cameron P. Clinical review of prehospital trauma deaths - the missing piece of the puzzle. Injury 2017;48(5):971–2.
[14] Chiara O, Cimbanassi S, Pitidis A, Vesconi S. Preventable trauma deaths: from panel review to population based-studies. World J Emerg Surg 2006;1(1):12.
[15] Janak JC, Sosnov JA, Bares JM, et al. Comparison of military and civilian methods for determining potentially preventable deaths: a systematic review. JAMA Surg 2018;153(4):367–75.
[16] Kleber C, Giesecke M, Tsokos M, Haas N, Buschmann C. Trauma-related preventable deaths in Berlin 2010: need to change prehospital management strategies and trauma management education. World J Surg 2013;5(37):1154–61.
[17] Girard E, Jegousso Q, Boussat B, et al. Preventable deaths in a French regional trauma system: a six-year analysis of severe trauma mortality. J Visc Surg 2018 (Article in-press).
[18] Ashour A, Cameron P, Bernard S, Fitzgerald M, Smith K, Walker T. Could bystander first-aid prevent trauma deaths at the scene of injury? Emerg Med Australas 2007;19(2):163–8.
[19] Ryan M, Stella J, Chiu H, Ragg M. Injury patterns and preventability in prehospital motor vehicle crash fatalities in Victoria. Emerg Med Australas 2004;16(4):274–9.
[20] Mercier E, Cameron PA, Smith K, Beck B. Prehospital trauma death review in the State of Victoria, australia: a study protocol. BMJ Open 2018;8(7) e022070.
[21] Nehme Z, Bernard S, Cameron P, et al. Using a cardiac arrest registry to measure the quality of emergency medical service care. Circ Cardiovasc Qual Outcomes 2015;8(1):56–66.
[22] Cameron PA, Finch CF, Gabbe BJ, Collins LJ, Smith KL, McNeil JJ. Developing Australia's first statewide trauma registry: what are the lessons? ANZ J Surg 2004;74(6):424–8.
[23] World Health Organization. Guidelines for trauma quality improvement programmes. Geneva, Switzerland: World Health Organisation, International Society of Surgery & International Association for Trauma Surgery and Intensive Care; 2009.
[24] Shackford SR, Hollingsworth-fridlund P, Mcardle M, Eastman A. Assuring quality in a trauma system-the medical audit committee: composition, cost, and results. J Trauma Acute Care Surg 1987;27(8):866–75.
[25] MacKenzie EJ, Steinwachs DM, Bone LR, Floccare DJ, Ramzy AI, Group PDS. Inter-rater reliability of preventable death judgments. J Trauma Acute Care Surg 1992;33(2):292–303.
[26] Vioque SM, Kim PK, McMaster J, et al. Classifying errors in preventable and potentially preventable trauma deaths: a 9-year review using the Joint Commission's standardized methodology. Am J Surg 2014;208(2):187–94.
[27] Oliver GJ, Walter DP. A call for consensus on methodology and terminology to improve comparability in the study of preventable prehospital trauma deaths: a systematic literature review. Acad Emerg Med 2016;23(4):503–10.
[28] Association for the advancement of automotive medicine. Abbreviated injury scale 2005 - update 2008. Barrington, Illinois: AAAM; 2008.
[29] McDermott FT, Cordner SM, Cooper DJ, Winship VC, CCoRTFi Victoria. Management deficiencies and death preventability of road traffic fatalities before and after a new trauma care system in Victoria, Australia. J Trauma Acute Care Surg 2007;63(2):331–8.
[30] Dyson K, Bray J, Smith K, Bernard S, Straney L, Finn J. Paramedic exposure to out-of-hospital cardiac arrest is rare and declining in Victoria, Australia. Resuscitation 2015;89:93–8.
[31] Amadi-obi A, Gilligan P, Owens N, O'donnell C. Telemedicine in pre-hospital care: a review of telemedicine applications in the pre-hospital environment. Int J Emerg Med 2014;7(29) (Online).
[32] Bulger EM, Snyder D, Schoelles K, et al. An evidence-based prehospital guideline for external hemorrhage control: American College of Surgeons Committee on Trauma. Prehosp Emerg Care 2014;18(2):163–73.
[33] Brown JB, Rosengart MR, Forsythe RM, et al. Not all prehospital time is equal: influence of scene time on mortality. J Trauma Acute Care Surg 2016;81(1):93–100.
[34] Harmsen A, Giannakopoulos G, Moerbeek P, Jansma E, Bonjer H, Bloemers F. The influence of prehospital time on trauma patients outcome: a systematic review. Injury 2015;46(4):602–9.
[35] Kaserer A, Stein P, Simmen H-P, Spahn DR, Neuhaus V. Failure rate of prehospital chest decompression after severe thoracic trauma. Am J Emerg Med 2017;35(3):469–74.

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[36] Fitzgerald M, Mackenzie C, Marasco S, Hoyle R, Kossmann T. Pleural decompression and drainage during trauma reception and resuscitation. Injury 2008;39(1):9–20.
[37] Lahausse JA, Fildes BN, Page Y, Fitzharris MP. The Potential for Automatic Crash Notification Systems to Reduce Road Fatalities. Paper Presented at: Annals of Advances in Automotive Medicine/Annual Scientific Conference. 2008.
[38] Garner AA, Lee A, Weatherall A, Langcake M, Balogh ZJ. Physician staffed helicopter emergency medical service case identification-a before and after study in children. Scand J Trauma Resusc Emerg Med 2016;1(24):1–7.
[39] Sinclair N, Swinton PA, Donald M, et al. Clinician tasking in ambulance control improves the identification of major trauma patients and pre-hospital critical care team tasking. Injury 2018;49(5):897–902.
[40] Shackelford SA, del Junco DJ, Powell-Dunford N, et al. Association of prehospital blood product transfusion during medical evacuation of combat casualties in Afghanistan with acute and 30-Day survival. JAMA 2017;318 (16):1581–91.
[41] Smith I, Crombie N, Bishop J, et al. RePHILL: protocol for a randomised controlled trial of pre-hospital blood product resuscitation for trauma. Transfus Med 2017.
[42] Van Vledder MG, Van Waes OJ, Kooij FO, Peters JH, Van Lieshout EM, Verhofstad MH. Out of hospital thoracotomy for cardiac arrest after penetrating thoracic trauma. Injury 2017;48(9):1865–9.
[43] Davies GE, Lockey DJ. Thirteen survivors of prehospital thoracotomy for penetrating trauma: a prehospital physician-performed resuscitation procedure that can yield good results. J Trauma Acute Care Surg 2011;70(5): E75–8.
[44] Sadek S, Lockey DJ, Lendrum RA, Perkins Z, Price J, Davies GE. Resuscitative endovascular balloon occlusion of the aorta (REBOA) in the pre-hospital setting: an additional resuscitation option for uncontrolled catastrophic haemorrhage. Resuscitation 2016;107:135–8.
[45] Burton JL, Underwood J. Clinical, educational, and epidemiological value of autopsy. Lancet 2007;369(9571):1471–80.

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