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Prehospital tourniquet use in civilian extremity trauma: an Australian observational study

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Abstract

Background: Prehospital tourniquets (PHTQ) for trauma have been shown to be safe and effective in the military environment and in some civilian settings. However, the supporting civilian data are mostly from North America with a differing case mix and trauma system and may not be applicable to the Australian environment. The aim of this study is to describe our initial experience with PHTQ from safety and efficacy viewpoints.

Method: Retrospective review of all patients with PHTQ from 1 August 2016 to 31 December 2019 was conducted. Data were matched from the RMH Trauma Registry and Ambulance Victoria Registry. Clinical presentation including prehospital observations, PHTQ times, limb outcomes and complications are described.

Results: Thirty-one cases met inclusion criteria, for whom median age was 37 (IQR: 23.9–66.3), median ISS 17 (13–34) and 80.6% were male. The majority ($n = 19$, 61.3%) were as a result of road traffic crash, and six (19.4%) from penetrating mechanisms, usually glass. Over a quarter (29.0%) suffered a traumatic amputation. The median prehospital SBP was 100 (IQR: 80–110), the median prehospital HR was 101 (IQR: 77.0–122.3) and was the median PHTQ time was 124 min (IQR: 47–243). Complications attributable to the tourniquet were seen in 4/30 cases (13.3%).

Conclusion: This Australian series differs from North American civilian PHTQ series with a lower penetrating trauma rate and longer PHTQ times. Despite this, complication rates are within the published literature's range. Concerns regarding limited transferability of overseas studies to the Australian context suggests that ongoing audit is required.

Introduction

Although tourniquets usage has been known since antiquity, the indications for prehospital tourniquet (PHTQ) usage remain challenging, as each application requires a sophisticated but instantaneous analysis of the competing priorities of haemorrhage control versus potential neurovascular damage from incorrectly applied or prolonged tourniquet usage. Prior to this century, PHTQ usage was generally out of favour, with one author describing them somewhat melodramatically as 'an instrument of the devil that sometimes saves a life' as recently as 2003.[1] Since then, successful use in the military[2–4] has renewed interest in the civilian sector, with three systematic reviews suggesting improved patient survival with PHTQ and acceptable complication rates.[5–7] However, studies from the military and civilian centres with predominantly North American urban geography and differing wounding mechanisms have limited generalizability to the Australian context, in which usage is not well described, with only low number of case reports published.[8,9] In August 2016, Ambulance Victoria (AV) introduced a PHTQ as a therapeutic option alongside a clinical practice guideline (CPG). The aim of this study was to describe the initial experience of PHTQ application in those admitted to the RMH in the first three and a half years of the protocol's implementation.

Methods

This study is a retrospective analysis of the Royal Melbourne Hospital (RMH) Trauma Registry and the Ambulance Victoria (AV) Registry. Inclusion criterion was all trauma patients presenting to the Royal Melbourne Hospital (RMH) with a tourniquet applied in the prehospital environment by a paramedical or medical first responder, from 1 August 2016 to 31 December 2019. The RMH is one of two adult Level 1 Major Trauma Centre in Victoria, Australia. RMH manages ~1200 major trauma admissions *per annum*. The Trauma Registry includes all patients who meet the Victorian Major Trauma Criteria.[10]

Ambulance Victoria utilizes the combat application tourniquet (CAT) for all levels of paramedic. The indications are for uncontrolled limb haemorrhage despite direct pressure or for situations where there are multiple casualties therefore individual haemorrhage control is not possible. The guideline recommends applying the CAT 5–7 cm proximal to the bleeding site, and not over a wound or a joint. It is recommended the time of application is written on the time strap and that it is not removed until medical clearance. If time exceeds 2 h before reaching a hospital, further medical advice is sought.

Case acquisition was via identifying tourniquet usage from both the Royal Melbourne Hospital Trauma Registry (RMH-TR) and AV registry. Data collected included demographics, prehospital vital signs, Emergency Department (ED) vital signs and laboratory parameters, Injury Severity Score (ISS), tourniquet placement and indication, transfusion requirement, and limb injury/abbreviate injury severity (AIS) score. Electronic Medical Records were reviewed to collect surgical treatment, and the outcome of both injured limb and patient. Complications attributable to PHTQ were searched for in both the RMH-TR and by case note review. The presence or absence of complications was assessed by detailed case-note review looking for any of the following terms (i) neuropraxia/sensory/motor loss, (ii) compartment syndrome, (iii) ischemia and/or reperfusion injury (iv) renal failure/impairment/injury, (v) soft tissue injury, then categorized. All available data sources were examined to calculate PHTQ time, and if there were a discrepancy, the longer time was used. Transport time was derived from RMH arrival time minus 'load time', a measure of ambulance departure time. Ambulance scene time was as recorded on the prehospital case record. The Emergency Department (ED) outcome of the PHTQ was categorized as either (i) removed no bleeding, (ii) removed direct pressure sufficed, (iii) removed and reapplied, (iv) left until angiography or (v) left until theatre. Categories 2–5 were combined under the variable 'Further Haemostatic Manoeuvre' required. These two categories were compared for factors available to the attending paramedic with *t*-test for parametric variables such as prehospital vital signs, and Wilcoxon rank sum for non-parametric values (ISS). It was considered that there were insufficient cases to subject the data to regression analysis.

Patients with more than one PHTQ were treated as one case, with the longest PHTQ time utilized for analysis if different. Continuous variables were summarized as median and interquartile range (IQR) and categorical variables as frequencies and percentages. Patients' groups were compared using Mann–Whitney test for continuous variables and chi-squared test or Fischer's exact test for categorical variables. A *P*-value of <0.05 was considered significant. Data were collected on a Redcaps database and analysed using Stata v16. Ethics approval was obtained both from Melbourne Health and Ambulance Victoria (HREC QA 2020150).

Table 1 Demographic and clinical features, $n = 31$

Age	Years, median, IQR	37.0 (12.9–66.3)
Sex	Male *n* (%)	25 (80.6)
Prehospital observations, median, (IQR)	SBP (mmHg)	100 (80–110)
	HR (bpm)	101 (77.0–122.3)
ED observation, median, (IQR)	SBP (mmHg)	110 (81.5–127.0)
	HR (bpm)	109.5 (90.0–128.8)
pH, median, (IQR)		7.22 (7.03–7.32)
Hb, median, (IQR)		127 (114.8–143.8)
LOS	Median, IQR	12.7 (2.5–21.6)
Other injuries#	Brain	6
	Neck and spine	7
	Chest	17
	Abdomen	8
	Pelvis	4
Any Blood transfusion, *n* (range)	Red cells	22 (2–26)
	FFP	12 (1–10)
	Platelets	11 (1–7)
	Cryoprecipitate	10 (1–20)

Results

Over the study period, 31 cases met the inclusion criteria. The demographics, indications and outcomes are presented in Table 1. The median age was 37 (IQR: 23.9–66.3), median ISS 17 (13–34) and 80.6% were male. Nineteen (61.3%) were as a result of a road traffic crash, three (9.7%) crushed in machinery, three (9.7%) from a fall from height, and six (19.4%) from a penetrating mechanism, usually glass. There were no gunshot wounds in this series. The median prehospital SBP was 100 (IQR: 80–110) and the median prehospital HR was 101 (IQR: 77.0–122.3).

The limb injury features included haemorrhage (83.9%), traumatic amputation (25.8%) and open fractures (32.3%). The majority (74.1%) had one PHTQ applied. The median limb AIS was three (IQR: 2–3). The majority (96.7%) of PHTQ have had no further bleeding on admission to RMH ED. For time related outcome measures and complications, one case was excluded as that tourniquet was kept in situ for a prolonged period to facilitate organ donation (Table 2). The median PHTQ time was 124 min (IQR: 196). Complications attributable to the tourniquet were seen in 4/30 cases (13.3%), with two (6.7%) patients with limb ischaemia and/or reperfusion injury, one (3.3%) temporary sensory deficit and one (3.3%) temporary combined motor and sensory deficit.

Of the 31 patients, 20 (64.5%) needed further haemostatic manoeuvres in the ED or Operating Theatre. Seven (22.6%) had their PHTQs removed and direct pressure applied which sufficed, four (12.9%) had their PHTQs removed and reapplied and nine (29.0%) went straight to operating theatre. Eight (25.8%) had major

Table 2 Prehospital tourniquet: indications and outcomes

		Number
Limb injury factors†	Haemorrhage	26
	Traumatic amputation	8
ISS	Median, IQR	17 (13–34)
AIS worst limb	Median, (IQR)	3 (2–3)
Tourniquet factors		
Number of tourniquets per case	One	23
	Two	6
	Three	1
	Four	1
Limb†	Upper	16
	Lower	23
Tourniquet time‡ minutes, $n = 26$	Median (IQR)	122 (47–243)
Scene time‡, minutes, $n = 22$	Median (IQR)	59 (48–104.8)
Transport time‡, minutes, $n = 22$	Median (IQR)	36 (17–252.8)
Outcomes		
Bleeding controlled on arrival to ED, *n* (%)	Yes	29 (96.7)
ED outcome of PHTQ *n* (%)	Straight to OT	9 (29.0)
	Angio	0 (0)
	Removed in ED, reapplied	4 (12.9)
	Removed in ED and direct pressure required	7 (22.6)
	Removed in ED no bleeding	11 (35.5)
Treatment of limb injuries, *n*	Interventional radiology	0
	Major vascular repair	8 (1 ligation, 4 repaired, 3 bypassed)
	Amputation	9
Complications, *n*	Limb ischaemia +/− reperfusion‡	2
	Neurological impairment	2 sensory and 1 motor
Mortality	*n* (%)	1 (3.2%)

†Multiple responses possible.

‡One case for organ donation excluded from analysis.

vascular injury, with four repaired, three bypassed and one ligated. Nine (29.0%) patients had their limbs amputated. Two (6.5%) had prophylactic fasciotomies and one (3.2%) had therapeutic fasciotomy. This patient's compartment syndrome was likely due to his injuries as he had prolonged extraction and was trapped by his legs for over 2 h. Table 3 compared those cases who required further haemostatic manoeuvres versus those who had no bleeding after removal of PHTQ. There was no difference between the prehospital BP and HR between the two groups. When BP and HR were categorized into binary variables suggesting the presence or absence of shock, a more clinically useful data point, there was once again no difference in the proportion of those with SBP < 100 (36.4% vs. 35.0%, $P = 0.46$), but more of those not requiring FHM's had a HR > 100 (72.5% v 45.0%, $P = 0.14$). There was no difference in ISS, limb AIS or tourniquet time between the two groups.

Discussion

To the authors' knowledge, this is the only Australian series of PHTQ use in civilian trauma, and hence can provide some context to the Australian environment. The major finding of this study is that the mechanism of injury substantially differs compared to civilian series from the USA, with only 19.4% of this series injured by penetrating mechanism, less than the 42.7–77% reported in published series (Table 4.) Furthermore, in the current series, there were no gunshot wounds, compared with 33% in the largest multicentre study from the USA.[11] It is noted that eight of 31 (25.8%) subsequently required a major vascular arterial procedure, and another nine (29.0%) had a traumatic amputation, suggesting the majority had a likely robust indication for PHTQ application. However, it was not possible to accurately assess the effectiveness of PHTQ application from the RMH database nor the electronic medical record, as there was limited documentation regarding the presence or absence of a distal pulse. We therefore used ongoing haemorrhage in ED and a measure of whether further haemostatic manoeuvres were required in the ED as surrogates.

Resurging interest in PHTQ use arose from military experience in the mid-2000s. Seminal work from Kragh[2,3] established safety and efficacy in the military environment, and notably found that tourniquets were more likely to be lifesaving when applied in the prehospital environment compared with in-hospital; and before onset of shock compared with after the onset of shock. This led to an interest in PHTQ in the civilian environment, particularly in North America. There have been three systematic reviews on PHTQs, and accepting substantial heterogeneity and bias, each has concluded PHTQ are safe and effective.[5–7] However, the data is dominated by studies from the USA, and in the most recent review,[6] only 14 cases from three studies originated from outside of the USA, which contributed 1417 cases from 14 studies. The substantially different patient population and geography when compared to USA civilian and international military series would bring into question the transferability to the Australian context, hence the rationale for this study, and indeed ongoing monitoring of future PHTQ applications.

To explore PHTQ time we compared to published civilian series in the last decade, with at least 10 cases, excluding mass casualty events, where PHTQ could be distinguished from in-hospital applied tourniquets (Table 4). In this series, the median PHTQ time was longer at 122 min than all comparable urban series (21–77.3 min, variably reported as mean or median), but was similar to one series from an Iowa Major Trauma Service (120 min) which serves a rural population,[12] potentially more comparable to the Australian context. We highlight that the most recent systematic review from Eilertsen[6] stated that the most average tourniquet times in the review were below 2 h. The current series' median was just over this time, implying that half had times over this clinically relevant threshold, which included all those cases with PHTQ attributable complications in this series. Given that experimental data suggests the risk of tourniquet related injury increases with application time, particularly over the 90–120 min threshold, continued monitoring of safety is warranted in this population.[13] The median scene time of 59 min and median transport time of 34 min in this

Table 3 Characteristics of patients who required further haemostatic manoeuvres versus those who did not

		ED tourniquet disposition		*P*-value
		PHTQ removed no bleeding $n = 11$	Further haemostatic manoeuvre required $n = 20$	
Prehospital SBP	Median (IQR)	120 (40)	105 (60)	$P = 0.44$
Prehospital HR	Median (IQR)	98 (44)	116 (50)	$P = 0.46$
Prehospital SBP < 100	*n* (%)	4 (36.4)	7 (35.0)	$P = 0.46$
Prehospital HR > 100	*n* (%)	8 (72.7)	9 (45.0)	$P = 0.14$
ISS > 12	*n* (%)	10 (90.1)	18 (90.0)	$P = 1.00$
AIS limb	Median (IQR)	2 (1)	3 (1)	
Tourniquet time† (min)	Median (IQR)	80 (41–119)	211 (97–326)	$P = 0.14$

†One case excluded as PHTQ kept on longer to facilitate organ donation.

Time, SBP, HR analysed via student's *t*-test. ISS analysed by Wilcoxon Rank Sum.

series could be cautiously interpreted as that a substantial proportion of the PHTQ time occurs in the prehospital phase. Nevertheless, the complication rate of 13.3% is within the range reported by one systematic review[5] of 1–29%, noting that only eight studies reported complications, and there was no established definition of what constitutes a tourniquet related complication. This difficulty is further compounded by observational stud design being unable at times to differentiate between ischaemic and neurologic complications caused by the injury versus the tourniquet.

We attempted to address the appropriateness of PHTQ placement, noting that there is no agreed definition of appropriate tourniquet usage in the civilian setting, and that Kauvar identified only two studies[7,14,15] that had assessed PHTQ appropriateness both utilising differing definitions. Given the complexity of deriving indication from observational data, we have chosen to categorize PHTQ outcome based on whether there was there ongoing bleeding upon presentation to ED for which there was not in the majority (96.7%); and based on the need for further haemostatic manoeuvres in ED, versus those in whom PHTQ was removed without consequence.

We also consider the use of what Lakstein[4] described as a 'tactical tourniquet' that is the use of a tourniquet where direct pressure could a have sufficed, but was impractical as the prehospital provider was required to attend to other tasks, for example, airway or scene management as appropriate. Hence, we therefore categorizing those cases where PHTQ were removed in ED and direct pressure sufficed as further haemostatic manoeuvre required. Twenty patients (64.5%) needed further haemostatic measures on arrival to ED, of which eight (25.8%) had major vessel injuries. The remaining 11 patients (35.5%) potentially had PHTQ placed due to venous bleeding (PHTQ removed in ED and had no further bleeding), and in retrospect may have potentially not required a PHTQ.

When analysed by at scene factors available to the prehospital provider, there was no difference in median heart rate or systolic blood pressure, nor for proxy measures of injury severity such as limb AIS and ISS between those requiring or not requiring further haemostatic manoeuvres. However, when prehospital vital signs were analysed for the potential presence or absence of shock, a more pragmatic approach as health providers do not tend to think in statistical measures, there was a higher proportion of those with a tachycardia for those not requiring further haemostatic manoeuvres compared with those that did. This seems counter intuitive but could be potentially explained by the hypothesis that a prehospital provider faced with a bleeding limb and a patient with a tachycardia, the first indicator of haemorrhagic shock, is more likely to apply a PHTQ. Given the evidence suggests that there is a morbidity and mortality benefit from applying a PHTQ before the onset of hypotension,[3] this seems an entirely justifiable action.

Having said that, there are two potential interpretations of these data showing a low rate of complications – that PHTQs are safe, or that they have been incorrectly applied. Our assessment of adequacy was only based upon the presence or absence of bleeding on presentation to ED, as data on peripheral pulses was insufficiently documented.

Table 4 Tourniquet time, limited to civilian series, $n > 10$, excluding bystander and in hospital applications were possible

Setting	Lead Author	Year	*n*	Average total tourniquet time (min)	Measure of spread (min)	Notes
Multicentre USA	Schroll[11]	2022	962	40	Range: 4–506	33% GSW 35.9% stab
Iowa, USA	Bedri[12]	2022	87	120	Range: 60–180	Rural population
New Orleans, USA	Smith[16]	2018	127	34.9	Sem 1.5	73.9% penetrating
Texas, USA	Teixeira[17]	2018	181	77.3	IQR: 39.0–92 SD ± 63.1	55.2% penetrating
Minnesota, USA	Leonard[18]	2017	61	21	Range: 4–142	Included 10 AV fistula bleeds, 42.7% penetrating
California, USA	Inaba[19]	2015	44	Median 72.0	IQR: 95.0	66.6% penetrating
North Carolina, USA	Ode[14]	2015	24	72	Range: 16–241	Includes 5 bystander, and 4 AV fistula bleeds
Victoria, Australia	Read (current series)	2023	26	Median 122	IQR: 47–447	19.5% penetrating

There are several limitations to this retrospective single-centre series. First, the total numbers are low at 31 over 4 years, limiting statistical analysis. Second, although all data have been entered contemporaneously, bias is possible either from interpretation or transcription form clinical data, noting that some data were missing. Complete case analysis was the default method of dealing with missing data. The authors felt that usual measures collected in a trauma registry were limited in assessing PHTQ's, and that a dedicated database is warranted. Thirdly, survival bias is also likely present, particularly as inclusion in this study is conditional upon survival to the Major Trauma Service, and it is feasible that PHTQ were applied in persons that did not survive retrieval to the RMH. Finally, external validity may be limited as the study is confined to one hospital in one trauma system. Improvised tourniquets by non-trained providers and tourniquets applied in the emergency department were not assessed in this study, so no inference can made about these interventions.

In summary, although these data show acceptable morbidity from PHTQ usage, tourniquet time is long, and the mechanisms of injury are different compared to the international civilian trauma data. The authors would recommend continued monitoring and have established a proforma to contemporaneously collect relevant details to further define the role in the local environment.

Conclusion

This series of PHTQs placed by prehospital healthcare providers shows a complication rate similar to the literature, but a long application time compared to most other civilian series. There was a low rate of penetrating injury and no gunshot wounds, which differs substantially from North American studies, raising doubt about the transportability of safety data to the Australian context. Continued monitoring of outcomes from PHTQ's is warranted, and consideration should be given to expanding trauma databases to collect relevant data points.

Conflict of interest

None declared.

Author contributions

David J Read: Conceptualization; formal analysis; methodology; project administration; supervision; writing – original draft; writing – review and editing. **Jessica Wong:** Formal analysis; writing – original draft; writing – review and editing. **Raine Liu:** Data curation; project administration; writing – review and editing. **Kellie Gumm:** Data curation; project administration; writing – review and editing. **David Anderson:** Data curation; project administration; writing – review and editing.

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