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Tourniquet use for peripheral vascular injuries in the civilian setting

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ABSTRACT

Background: Haemorrhage in peripheral vascular injuries may cause life-threatening exsanguination. Tourniquets are used extensively by the military, with increased interest in the civilian setting to prevent deaths. This is a retrospective study of trauma patients at two large Canadian trauma centres with arterial injury after isolated extremity trauma. We hypothesized that tourniquet use may decrease mortality rate and transfusion requirements if applied early.

Methods: The study group was all adult patients at two Level 1 Trauma Centres in two Canadian cities in Canada, who had arterial injuries from extremity trauma. The study period was from January 2001 to December 2010. We excluded patients with significant associated injuries. The intervention in this study was prehospital tourniquet use. The main outcome was in-hospital mortality. Secondary outcomes were length of stay, compartment syndrome, amputation, and blood product transfusion.

Results: 190 patients were included in the study, and only 4 patients had a prehospital tourniquet applied. They arrived directly from the scene of injury, had improvised tourniquets by police or bystanders, and showed a trend to be more hypotensive and acidotic. Four other patients had tourniquets applied in the trauma bay within 1 h of injury. There were no differences in age, sex, injury severity or physiologic presentation between patients who had an early tourniquet applied and those who died without a tourniquet. However, six patients died without a tourniquet, and all bled to death. Of the eight patients who had early tourniquets applied, none died.

Conclusions: Tourniquets may prevent exsanguination in the civilian setting for patients suffering either blunt or penetrating trauma to the extremity. Future studies will help determine the utility of deploying tourniquets in the civilian setting, given the rarity of exsanguinating haemorrhage from isolated extremity trauma in this setting.

Introduction

Haemorrhage is a leading cause of death in trauma patients [1,2]. Peripheral vascular injuries are common on the battlefield, but can also occur in the civilian setting. If haemorrhage is not controlled quickly, peripheral vascular injuries have the potential to cause life-threatening exsanguination. This is particularly true in the military setting and in rural, civilian areas, where the prompt definitive control of bleeding may be difficult [3–5].

Tourniquets are now used extensively by the military [6–12]. However, traditional civilian trauma training has frowned on tourniquet use. Advanced Trauma Life Support® recommends compression as the first line treatment for bleeding extremity wounds; an example of this treatment may include application of a tight bandage directly over a wound [13]. However, on some occasions, the application of a proper bandage may be time-consuming and technically more challenging than placing a tourniquet [12]. Furthermore, direct compression with a bandage may not completely control major arterial haemorrhage. For these reasons, and in the setting of long prehospital transport times, the tourniquet may be the instrument of choice to achieve temporary prehospital control of life threatening haemorrhage from the extremity [4].

One of the major reasons why the military has adopted tourniquets for the battlefield was Bellamy's epidemiological studies of causes of death of US service personnel during the Vietnam War [14,15]. More specifically, many US service personnel died during the Vietnam War solely from exsanguination from extremity wounds. As a result, Butler and colleagues devised a

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system of prehospital care called Tactical Combat Casualty care, which called for the use of tourniquets on the battlefield [16].

Several studies outline both the morbidity and mortality following civilian extremity vascular injuries. Feliciano believes that tourniquets will soon become more commonly used by civilian emergency medical services [17]. In an excellent review of civilian patients who suffered cardiac arrest after penetrating extremity injury, Dorlac suggested that 57% were possibly preventable deaths, if tourniquets had been applied early [18]. Unfortunately, most civilian studies on tourniquet use have focused on penetrating injuries. Therefore, these studies do not document the full scope of the challenge in civilian trauma systems, as blunt mechanisms constitute the majority of traumatic injuries in North America [2]. As such, we performed a retrospective cohort study of all trauma patients at two large Canadian trauma centres who sustained arterial injury after isolated extremity trauma, from either blunt and penetrating mechanisms. We compared the mortality of patients who were treated with prehospital tourniquet use versus those who were not. We also examined all deaths in patients who did not have an early tourniquet application to determine if early tourniquet application may have altered survival. We hypothesized that early tourniquet use would be associated with decreased mortality and transfusion requirements in patients with isolated extremity arterial injuries.

Methods

Setting

The trauma registries at two large Level 1 Trauma Centres in Canada were used to identify all trauma patients evaluated from January 1, 2001 to December 31, 2010.

Inclusion criteria

The study group consisted of all adult patients (age 16–90 years old) with arterial trauma from isolated limb extremity injuries, via either penetrating or blunt mechanisms. These patients were identified using the following methodology:

(i) trauma registries were used to identify all patients with abbreviated injury score (AIS) of 3 or higher in the extremities, from either blunt or penetrating mechanisms; and
(ii) chart review was performed to identify patients with arterial injuries that required either revascularization surgery, or limb amputation. Patients were included whether or not they had associated other injuries to the extremity, such as bony, nerve, or soft tissue injury.

Exclusion criteria

We excluded all patients with AIS of their head/neck, chest, abdomen and pelvis of 3 or higher. We excluded these patients because we wished to analyze for possible mortality benefits of tourniquet use; severe brain injury and torso haemorrhage cause the majority of trauma deaths and would not be helped by tourniquet use. We also excluded patients with isolated venous injuries in their extremities, as these injuries should be adequately treated with compression. We also excluded burns, and patients injured in the military setting and who were transferred to our facilities for reconstructive care.

On chart review, we confirmed the accuracy of this methodology by ensuring that no patients with any other major sources of haemorrhage were included in the study cohort; we did this by confirming that no patients were included who required thoracotomy, chest tube insertion, laparotomy or angiography for torso bleeding. We also confirmed that no patients had severe brain injury that required craniotomy, or who died because of withdrawal of care. Our study cohort included patients admitted direct from the scene of injury, and those referred from a community hospital.

Intervention

The intervention in this study was prehospital tourniquet use. We performed chart review of both the EMS record and the initial trauma room record to determine if (i) a tourniquet was applied in the field; or (ii) if the patient arrived in the trauma room with a tourniquet.

Outcomes

The main outcome for this study was in-hospital mortality. Secondary outcomes included length of stay (LOS), Intensive Care Unit (ICU) stay, compartment syndrome, amputation, and units of blood products transfused. These outcomes were determined by a combination of electronic health record review, and focused "paper chart review".

Patient demographics, injury mechanism, Injury Severity Score (ISS), Abbreviated Injury Scale Scores (AIS), length of hospital stay (days), intensive care unit stay (days), total units of blood transfused, and in-hospital outcome (dead/alive) were determined from our trauma registry. ISS and AIS were calculated by trauma registry staff after discharge or death of each patient. This study was approved by institutional review ethics boards at both sites. Type of vascular injury, need for revascularization, and need for amputation were confirmed on review of operative reports.

Descriptive statistics were performed. Continuous data was presented using means and standard deviations, and compared using *T*-test. Categorical data was presented as proportions, and compared with Chi-square test, or Fisher's exact test. *P*-values were two-tailed. Statistic analysis was performed using SAS software (SAS version 9.2, SAS Institute Inc., North Carolina, USA).

Results

During the 10-year study period, 19,977 total patients were evaluated by our trauma services (Sunnybrook: 10,599; Foothills: 9378). Of these, 360 suffered arterial injuries to the limb that required revascularization surgery or amputation. We excluded 101 patients who had thermal injuries, electrical burns, transfer from another province or country, and military patients. We also excluded 69 patients with Abbreviated Injury Score for head and neck, chest, abdomen and pelvis equal or greater than 3. Our final cohort consisted of 190 patients who suffered isolated extremity injuries with arterial injury (119 from Sunnybrook and 71 from Foothills). We checked the accuracy of our methodology during review of the operative and discharge notes. None of these patients required laparotomy, tube thoracostomy, thoracotomy or embolization for bleeding. Our sample consists mostly of men (85%). Sixty eight percent of patients were brought directly from the scene of injury and 32% were transferred from a referring centre. Most of our patients suffered blunt trauma to the extremity. Baseline characteristics of the study group are presented in Table 1.

One hundred eighty-six patients arrived without prehospital tourniquet. Only four patients presented with a tourniquet present upon arrival. These four patients were all transferred to our hospitals directly from the scene of injury, and all four had improvised tourniquets by police or bystanders. Two patients suffered penetrating injuries, and two suffered blunt trauma. One of these patients had suffered a prehospital cardiac arrest, and cardio-pulmonary resuscitation (CPR) had been started. We were

Table 1
Baseline characteristics.

	No tourniquet	Pre-hospital tourniquet	*P* value
Number	186	4	
Age	36 ± 16	41 ± 12	0.6
% Male	84%	100%	0.5
ISS	16 ± 10	17 ± 7	0.8
Prehospital time (min)	103 ± 122	91 ± 72	0.8
% Penetrating	28%	50%	0.1

ISS: injury severity score.

only able to find data on the types of improvised tourniquet used for 3 of the 4 patients. In one case, a neck tie was used as an improvised tourniquet. In two other cases, a belt and a handkerchief were used. On average, there were no significant differences between the groups. There was a strong trend, however, suggesting that patients who had prehospital tourniquets applied presented to the trauma room slightly more hypotensive and acidotic, and with a lower Glasgow Coma Scale (GCS) than the group who did not have a prehospital tourniquet. However, with only four patients in the tourniquet group, the differences were not statistically significant. See Table 2.

All patients from prehospital tourniquet group survived. Two patients sustaining blunt trauma that had prehospital tourniquets underwent limb amputation due to a mangled extremity or near amputation. No patient with a prehospital tourniquet developed compartment syndrome, nor needed massive transfusion (Table 3).

Four patients had a tourniquet applied in trauma bay, and these were all applied within 1 h of injury. These tourniquets were pneumatic blood pressure cuffs. Two of patients presented with blunt trauma causing "below the knee amputations"; one had blunt trauma causing a "below the elbow amputation", and another one had a stab wound to the forearm. Therefore, a total of 8 patients had early tourniquets placed, either at the scene ($n = 4$) or in the trauma bay ($n = 4$). We then compared these patients against the subgroup of patients who did not get a tourniquet, and who died. We did this to try to reduce the impact of indication bias, as first responders probably applied tourniquets to patients who were hemodynamically unstable and obviously bleeding.

Table 2
Physiologic status on arrival in the trauma room.

	No tourniquet	Pre-hospital tourniquet	*P* value
Number	186	4	
Systolic blood pressure	127 ± 30	99 ± 34	0.07
Heart rate	103 ± 26	99 ± 27	0.8
Arterial blood gas pH	7.33 ± 0.13	7.18 ± 0.22	0.07
GCS	15 ± 1	11 ± 7	0.08

GCS: Glasgow Coma Scale.

Table 3
Patient outcomes.

	No tourniquet	Pre-hospital tourniquet	*P* value
Number	186	4	
Units of PRBC (24 h)	6 ± 9	4 ± 2	0.25
Units of FFP (24 h)	2 ± 4	1.5 ± 3	0.8
Units of platelets (24 h)	1 ± 4	1 ± 2	0.9
LOS (days)	21 ± 21	22 ± 31	0.9
Compartment syndrome (%)	15.5	0	0.6
Amputation (%)	32.8%	50%	0.6
Death (%/*n*)	3.2% (*n* = 6)	0	0.9

PRBC: packed red blood cell; FFP: fresh frozen plasma; LOS: length of stay.

Table 4
Comparison of patients who died without tourniquet and patients who had early tourniquet.

	No tourniquet and died	Early tourniquet applied	*P* value
Number	6	8	
Age	45.1 (+/−14.0)	44.5 (+/−14.8)	0.9
ISS	23.8 (+/−16.2)	15.4 (+/−12.2)	0.47
Units of PRBC (24 h)	13.5 (+/−12.8)	3.6 (+/−2.1)	0.04
Units of FFP (24 h)	7.7 (+/−8.4)	0.75 (+/−2.1)	0.04
Units of platelets (24 h)	4.7 (+/−6.4)	0.5 (+/−1.4)	0.09
MT (%)	50%	0	0.05
Heart rate	110 (+/−30.3)	89.2 (+/−23.2)	0.2
Blood pressure	97.8 (=/−26.2)	109.4 (+/−33.6)	0.5
pH	7.31 (=/−0.05)	7.29 (+/−0.18)	0.86

MT: massive transfusion (10 or more PRBCs in 24 h).

All patients who had a tourniquet applied early (prehospital or in the trauma bay) survived. There were no differences in age, sex, injury severity or physiologic presentation between patients who had an early tourniquet applied, and those who died without a tourniquet. Both groups were acidotic. However, the cause of patients who died without a tourniquet was exsanguination. These patients received significantly more blood products (red blood cells and fresh frozen plasma – FFP), than those who had early tourniquets applied. Also, there was a very strong trend ($p = 0.05$) suggesting that patients who died without a tourniquet were more likely to get a massive transfusion than those who had early tourniquet applied. See Table 4.

Discussion

This retrospective cohort study comprised 190 trauma patients at two major Canadian trauma centres with isolated extremity trauma and associated arterial injury requiring either revascularization or amputation. There was no systematic use of tourniquets in the prehospital setting. Only four tourniquets were applied in this setting, and these were all improvised tourniquets applied by bystanders or police. There were no significant differences in mortality between patients who had prehospital tourniquets and those who did not.

Comparison between groups is clearly limited by the small number of patients who received prehospital tourniquets ($n = 4$). Also, most patients with arterial injuries were not actively bleeding (contained hematomas). In total, only six patients died out of the 190, which made comparison of mortality problematic between the two groups. It is interesting to note however that we did observe some trends suggesting a difference in baseline physiology between these two groups.

Apart from mortality, we also studied the effect of early tourniquet use on transfusion requirements. We did not find a statistically significant difference in transfusion rates in patients who had early tourniquet use vs. no tourniquet use. We did note, however, that there was a trend suggesting that transfusion requirement in the no tourniquet group was higher than in the early tourniquet group. There are likely two major reasons why we did not detect a statistically significant difference: one reason is that our numbers of early tourniquet use were small in this study; the second reason is that many patients in both groups were not freely exsanguinating. Therefore, for many patients, the transfusion requirement was low in both groups. Transfusion requirement, however, would be an important outcome to look at further. In the patients who were freely exsanguinating from extremity vascular trauma, the differences in transfusion requirement might be quite substantial, even though no mortality difference was detectable. According to our hypothesis, we would expect this to be more evident in the group with no tourniquet use. In our study,

we see that the "no tourniquet group" did have require more blood products, although the difference was not statistically significant ($p = 0.25$). Also, we did note that the standard error in the estimation of units required was quite high (6 +/− 9 units), suggesting that some of the patients in this group required substantial transfusion. Finally, in Table 4, we noted that patients who died without a tourniquet applied required massive transfusions, suggesting that they exsanguinated from their extremity vascular injury. From this, wonder if early tourniquet use would have prevented exsanguination.

Indication bias is another systematic error which this study is potentially subject to. Indication bias caused by a potential mix-up between cause and effect when exposure is dependent on indication. For example, indication bias occurs when a treatment is given to people at high risk of acquiring an outcome, potentially causing a preponderance of treated people among those with the outcome of interest [19,20]. In the case of tourniquet use, it is likely that improvised tourniquets were applied to patients who were actually more likely to die (the outcome of interest) because they were actively exsanguinating from their injury. If tourniquets were actually life-saving, then this bias would be a bias towards the null hypothesis, showing no difference in outcomes in patients who had prehospital tourniquets compared to those who did not.

To reduce the impact of these issues, we analyzed all patients who had early tourniquet use: those who had prehospital and trauma bay tourniquets applied and compared them to the patients who died without tourniquet use. There were a total of eight patients who had early tourniquet use. There were no differences noted between these patients in terms of their demographics, injury severity scores, or their physiology on presentation to the trauma room. However, as we pointed out previously, patients who died without tourniquets were more likely to have received massive transfusion, as well as more red cells and FFP transfusions compared to those patients who had early tourniquet application. As a result, early tourniquet application may reduce the chance of exsanguination from significant arterial injuries in patients with isolated extremity trauma, from either blunt or penetrating mechanisms.

We also note that tourniquet use was not associated with increased compartment syndrome and amputation. We observed a significant number of cases of compartment syndrome and amputation in patients who did not have tourniquets applied. We conclude that compartment syndrome and amputation are associated with the severity of trauma to the injured limb in the civilian setting and possibly the subsequent resuscitation, not the application of tourniquets [21].

Well known by its use in military setting and in orthopaedic surgery procedures, tourniquets have been associated with morbidity and even mortality [22], especially when used for prolonged time periods [23,24]. Sometimes called the "instrument of the devil", tourniquets were previously used for questionable indications, left on for prolonged periods, resulting in complications [25]. Among the more common or significant complications were compartment syndrome, deep vein thrombosis, skin injuries, and neurological complications [26,27]. However, no increases in DVT rates were observed when tourniquets were used in the operative setting [28]. The use of tourniquets in total knee arthroplasty cases was associated with local thrombogenic and fibrinolytic activity, but without systemic changes in thrombosis or fibrinolysis. Systemic activation of thrombosis and fibrinolysis was only noted after tourniquet release, presumably from release of local inflammatory mediators from the injured limb after restoration of perfusion [29].

Clasper et al. studied tourniquet use on the battlefield, and showed a significant difference in the incidence of major complications between prehospital tourniquet application and no prehospital tourniquet, especially related to a deep infection rate of 32% vs. 4.5% [30]. Lee studied intraoperative use of the pneumatic tourniquet, and described complications such as nerve paralysis and vascular injuries, and rhabdomyolysis after prolonged application without a mid-application release [31]. Likewise, Dayan et al. reported cases where improper and prolonged use of tourniquets caused complications such as nerve paralysis and limb ischaemia, reinforcing that proper training is indeed required to use a broad pneumatic tourniquet, with deflation required each 2 h for reassessment [24]. This complication may be avoided by using a new tourniquet system that determines pressures in synchrony with systolic blood pressure [32]. On the other hand, Kragh showed no complication related to tourniquet use on the battlefield even with prolonged use [10], and found that the benefits outweighed the risks when applied on the battlefield, especially before the onset of shock [8].

There was significant interest in fasciotomy rates after tourniquets were fielded in 2005. Kragh showed an increase in fasciotomy rates, and he found an association between tourniquet use, awareness of the need for fasciotomy as a prophylactic procedure, and an increase in ISS [37]. In our study, none of patients that had tourniquet applied in the prehospital setting or in trauma room developed compartment syndrome.

Most studies on tourniquet use during recent conflicts in Afghanistan and Iraq have shown the value of tourniquet use in the prehospital setting for limb injuries. Previously published series advocate its use because of lifesaving benefits with minor morbidity [8,21,33,34]. Despite finding complications associated with prehospital tourniquet use, Clasper wrote that prehospital tourniquet use may prevent up to 7% of combat deaths [30]. In a retrospective study, Beekley [35] showed that up to 57% of combat deaths could have been prevented by tourniquet use. Tien et al. showed that tourniquet use saved lives on the battlefield, despite cases of misuse and overuse [7]. Currently, these devices have become the first line treatment in battlefield for limb haemorrhage [36].

There is increasing interest in adopting tourniquets for prehospital use in the civilian setting [38,39]. Based on these scientific studies and based on the success in the military setting, in July 2012, an Adult Traumatic Haemorrhage Control Protocol was introduced to all Emergency Medical Service providers in the province of Alberta, Canada. This protocol advises the use of a CAT® (available: http://combattourniquet.com) tourniquet for uncontrolled extremity bleeding (available: http://www.albertahealthservices.ca/hp/if-hp-ems-mcp.pdf). Evaluating the effect of this protocol implementation should provide important information on the real-world utility of using such a device in the civilian trauma setting.

Conclusion

In this retrospective cohort study of patients with isolated extremity trauma and arterial injuries from either blunt or penetrating mechanisms, all deaths in the "no tourniquet" group were a direct result of exsanguination. Conversely, no patient with early tourniquet use died from exsanguination despite presenting with extensive physiologic compromise. We therefore conclude that tourniquet use in the civilian setting may prevent deaths from isolated extremity vascular trauma. Future studies, such as evaluating the impact of a province-wide prehospital haemorrhage control algorithm incorporating standardized tourniquet use, will help determine the utility of deploying tourniquets in the civilian setting, given the rarity of exsanguinating haemorrhage from isolated extremity trauma in this setting.

Conflict of interest statement

No authors have any conflict of interests to report.

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