Tourniquet use for civilian extremity trauma

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BACKGROUND: Unlike in the military setting, where the use of tourniquets has been well established, in the civilian sector their use has been far less uniform. The purpose of this study was to examine the outcomes associated with the use of tourniquets for civilian extremity trauma.

STUDY DESIGN: Adult (≥18 years) patients admitted to our institution with an extremity injury requiring tourniquet application from January 2007 to June 2014 were retrospectively reviewed. The primary outcome analyzed was limb loss. Secondary outcomes included death, hospital length of stay, and complications.

RESULTS: There were 87 patients who met inclusion criteria. Average age was 35.3 years, 90.8% were male, and 66.7% had penetrating injuries, with a median Injury Severity Score (ISS) of 6. Tourniquets were placed in the prehospital setting in 50.6%, in the emergency department in 39.1%, and in the operating room in 10.3% of patients. The windlass type Combat Application Tourniquet was the most commonly used type (67.8%), followed by a pneumatic system (24.1%) and self-made tourniquet (8.0%). The median duration of use was 75 minutes (interquartile range, 91) with no differences between groups ($p = 0.547$). Overall, 80.5% had a vascular injury (70.1% arterial), and a total of 99 limb operations were performed, including 15 amputations. Fourteen amputations (93.3%) occurred at the scene or were directly attributed to the extent of tissue damage with a median Mangled Extremity Severity Score (MESS) of 7 (interquartile range, 2). In the remaining patient, the tourniquet was lifesaving but likely contributed to limb loss. Seven patients sustained 13 other complications; however, none was directly attributed to tourniquet use.

CONCLUSION: Tourniquet use in the civilian sector is associated with a low rate of complications. With the low complication rate and high potential for benefit, aggressive use of this potentially lifesaving intervention is justified. (*J Trauma Acute Care Surg*. 2015;79: 232–237. Copyright © 2015 Wolters Kluwer Health, Inc. All rights reserved.)

LEVEL OF EVIDENCE: Epidemiologic/prognostic study, level III.

KEY WORDS: Tourniquet; vascular injury; shock control.

After injury, hemorrhage control is of paramount importance and is the critical first step for all trauma care providers. For extremity hemorrhage control, the use of tourniquets is not a new concept. Although exacting historic details are lacking, compressive devices designed to control extremity hemorrhage have been in use for centuries.[1] The vast majority of the contemporary literature base supporting the use of tourniquets has been produced by combat casualty care providers.[2–9] It is clear from these reports that tourniquet use is associated with improved survival and a low complication rate. At all levels of care, tourniquet use has become ubiquitous within the military medical system. In the civilian sector however, until recently, tourniquet use has been far less uniform, and consequently, there is a paucity of data describing the epidemiology of their use and outcomes. The controversy[10,11] underlying the use of tourniquets for civilian extremity trauma stems in large part from the purported differences between civilian and military injuries. Civilian patients have more consistent and rapid access to prehospital care providers, with abbreviated transport times and are being cared for by emergency medical service (EMS) providers who are not under fire and can therefore focus all of their efforts on hemorrhage control if required. In addition, because of the relative lack of high-energy penetrating injuries and explosions, which have been reported in upwards of half or more of the injuries requiring tourniquets in the combat setting, the injury burden seen in civilian extremity injuries is also less. Nevertheless, even in civilian practice, severe extremity injury with major vascular hemorrhage is not uncommon, and as has been demonstrated for the military patient population,[12,13] Dorlac et al.[14] have demonstrated that civilian patients are at risk of dying from isolated extremity injuries amenable to tourniquet control. A recently published Eastern Association for the Surgery of Trauma Practice Management Guideline[15] as well as an Evidence Based Prehospital Guideline for External Hemorrhage Control prepared by the American College of Surgeons' Committee on Trauma (ACS COT)[16] both recommend the use of tourniquets if hemorrhage is uncontrollable by direct pressure. The majority of the data used to formulate these recommendations however were derived from the military evidence base. In the more recent ACS COT guidelines,[16] only a single civilian series consisting of 11 patients was available for inclusion. Subsequently, to the best of our knowledge, only one additional civilian study from Canada with a total of eight patients who had a tourniquet applied over a 10-year period has been published. There is therefore a major lack of published data examining contemporary civilian practice with respect to tourniquet use for extremity hemorrhage.

The purpose of this study was therefore to examine the use of tourniquets in the civilian sector, with a particular focus on the epidemiology of use and outcomes, in those with and those without a significant vascular injury.

PATIENTS AND METHODS

After institutional review board approval was obtained, the trauma registry of the Los Angeles County + University of Southern California Hospital was retrospectively reviewed to identify all adult (≥18 years old) patients sustaining extremity injury from January 2007 to June 2014. A chart review was performed to identify all trauma patients who had tourniquet application in the prehospital setting, emergency department (ED), or operating room (OR). A tourniquet was defined as any constrictive device placed on an extremity in an attempt to decrease bleeding.

Data abstracted included age, sex, initial systolic blood pressure, initial heart rate, Injury Severity Score (ISS), Abbreviated Injury Scale (AIS) score for each body region (head, chest, abdomen, and extremity), laboratory values (hemoglobin, hematocrit, platelet count, international normalized ratio, pH, bicarbonate, and base deficit on admission) and injury mechanism. Tourniquet details including location of placement (prehospital, ED, or OR), duration of tourniquet application (in minutes), type

TABLE 1. Demographics and Clinical Presentation

Demographics and Clinical Presentation	All Patients (n = 87)	Blunt (n = 29)	Penetrating (n = 58)	*p*
Age, mean (SD), y	35.3 (12.5)	40.9 (13.0)	32.5 (11.3)	0.002
Male, n (%)	79/87 (90.8)	27/29 (93.1)	52/58 (89.7)	0.713
SBP, mean (SD), mm Hg	124.6 (27.6)	121.1 (31.4)	126.5 (25.5)	0.399
SBP < 90 mm Hg, n (%)	9/85 (10.6)	5/29 (17.2)	4/56 (7.1)	0.263
HR, mean (SD), bpm	93.9 (26.8)	96.7 (27.2)	92.5 (26.7)	0.493
HR > 110 bpm, n (%)	25/86 (29.1)	9/29 (31.0)	16/57 (28.1)	0.805
ISS, median (IQR)	6 (8)	10 (10)	4 (8)	<0.001
ISS ≥ 16, n (%)	8/87 (9.2)	7/29 (24.1)	1/58 (1.7)	0.002
Head AIS score ≥ 3, n (%)	3/87 (3.4)	2/29 (6.9)	1/58 (1.7)	0.257
Chest AIS score ≥ 3, n (%)	6/87 (6.9)	5/29 (17.2)	1/58 (1.7)	0.015
Abdomen AIS score ≥ 3, n (%)	2/87 (2.3)	2/29 (6.9)	0/58 (0.0)	0.109
Extremity AIS score ≥ 3, n (%)	34/87 (39.1)	22/29 (75.8)	12/58 (20.7)	<0.001
Hemoglobin on admission, mean (SD), mg/dL	11.7 (3.7)	11.5 (4.5)	11.9 (3.3)	0.622
Platelet on admission, mean (SD), $\times 10^9$/L	225 (73)	215 (75)	229 (72)	0.421
INR on admission, mean (SD)	1.2 (0.3)	1.2 (0.3)	1.2 (0.2)	0.405
pH on admission, mean (SD)	7.32 (0.10)	7.30 (0.11)	7.33 (0.09)	0.259
HCO_3^- on admission, mean (SD), mmol/L	18.5 (3.7)	18.4 (4.6)	18.5 (3.2)	0.927
BD on admission, mean (SD), mEq/L	6.8 (4.4)	7.2 (5.5)	6.5 (3.8)	0.578

BD, base deficit; HCO_3^-, bicarbonate; HR, heart rate; SPB, systolic blood pressure.

of tourniquet used (windlass Combat Application Tourniquet [CAT], pneumatic, or self-made], need for transfusion, and total blood products used were collected. Extremity injury details including the presence of vascular injury, Mangled Extremity Severity Score (MESS), and operative procedures were also collected.

Patient charts were reviewed to abstract all complications potentially related to the use of a tourniquet, including nerve palsy, myonecrosis, vascular thrombosis, compartment syndrome, acute renal failure, soft tissue damage, and amputation. The primary outcome analyzed was limb loss. Secondary outcomes included death, hospital length of stay (LOS), and complications occurring during the hospital stay.

The study population was stratified according to the mechanism of injury (blunt vs. penetrating) as well as the location of placement (prehospital, ED, or OR).

Continuous variables were dichotomized using clinically relevant cutoff points (age ≥ 55 years, systolic blood pressure ≤ 90 mm Hg, heart rate ≥ 110 beats/min [bpm], ISS ≥ 16, AIS score ≥ 3).

Demographics, clinical characteristics, and outcomes were compared using bivariate analysis. Student's *t* test and Mann-Whitney U-test were used for continuous variables, while χ^2 test and Fisher's exact test were used for categorical variables. A *p* value of 0.05 was considered statistically significant. All statistical analyses were performed using IBM SPSS Statistics for Mac version 20.0 (SPSS Inc., Armonk, NY).

RESULTS

During the study period, 87 patients had a tourniquet applied in the prehospital setting, ED, or OR. The mean age of the study cohort was 35.3 years (range, 18–72 years), 90.8% were male, with a mean (SD) ISS of 8.3 (8.0), and 66.7% sustained a penetrating injury. The blunt trauma patients were older, with a higher ISS, chest AIS score, and extremity AIS score, as shown in Table 1.

More than half of the patients sustained a stab wound, caused by either a blade (31.0%) or glass (20.7%). Overall, 11.5% of the study population sustained a work-related injury, primarily due to industrial machinery, and 8.0% were self-inflicted. Tourniquets were placed in the prehospital setting in 50.6%, the ED in 39.1%, and the OR in 10.3% of patients. Tourniquets were applied to 62 upper extremities and 25 lower extremities. Only single-extremity injuries requiring tourniquet use were observed with only a single tourniquet being used in each of the cases.

The mean (SD) duration of tourniquet use was 103.2 (99.6) minutes (range, 5–606 minutes) and was not significantly different between those placed in the prehospital setting, ED, or OR ($p = 0.547$). The prehospital transportation time for those who had a tourniquet applied in the field was 35 minutes (range, 9–90 minutes). The CAT was the most commonly applied tourniquet in the prehospital (68.2%) and ED setting (85.3%), while in the OR, a pneumatic tourniquet was used exclusively. In seven patients, a self-made tourniquet was applied by a patient, relative, or coworker before EMS arrival. Upon arrival to the ED, this was replaced with a CAT tourniquet in two of these patients. Tourniquets were placed with increasing frequency on limbs with a named vascular injury, increasing from 70.5% in the prehospital setting to 88.2% in the ED and 100% in the OR. Overall, 80.5% of patients had a vascular injury. This included 79 arterial and 19 venous injuries (Table 2). The MESS and the rate of limb loss did not differ between groups (Table 3).

Overall, 68 of the patients (78.2%) underwent at least one operative procedure, with the remainder requiring local wound care only. As shown in Table 4, a total of 99 limb operations were performed in the 68 patients. This included 15 amputations. Fourteen (93.3%) of these amputations were performed in patients with a severely mangled extremity, with a mean (SD) MESS of 7.6 (1.4) (range, 5–10). All had active soft tissue or

TABLE 2. Major Venous and Arterial Injuries

Vessel	Artery (n = 79)	Vein (n = 19)
Axillary	1	1
Basilic		4
Brachial	14	6
Digital	4	
Femoral	5	1
Peroneal	7	
Popliteal	7	1
Radial	16	
Saphenous		6
Tibial	7	
Ulnar	18	
Total	79	19

TABLE 3. Tourniquet's Characteristics

Variable	All Patients (n = 87)	Field (n = 44, 50.6%)	ED (n = 34, 39.1%)	OR (n = 9, 10.3%)	*p*
Time on, median (IQR), min	75.0 (91.0)	72.0 (95.0)	85.0 (95.0)	59.0 (101.0)	0.547
Need for transfusions, n (%)	41/87 (47.1)	17/44 (38.6)	20/34 (58.8)	4/9 (44.4)	0.221
Total blood products					
PRBC, mean (SD) (range)	4.1 (3.5) (1–16)	3.6 (3.7) (1–16)	4.6 (3.6) (1–16)	3.5 (2.4) (2–7)	0.676
FFP, mean (SD) (range)	3.9 (3.2) (1–9)	3.2 (3.5) (1–9)	4.9 (3.2) (1–9)	1.0 (0.0) (1–1)	0.475
Platelet, mean (SD) (range)	2.0 (1.0) (1–3)	3.0 (0.0) (3–3)	1.5 (0.7) (1–2)	—	0.333
Type of tourniquet					
CAT, n (%)	59/87 (67.8)	30/44 (68.2)	29/34 (85.3)	0/9 (0.0)	<0.001
Pneumatic, n (%)	21/87 (24.1)	7/44 (15.9)	5/34 (14.7)	9/9 (100)	<0.001
Other, n (%)	7/87 (8.0)	7/44 (15.9)	0/34 (0.0)	0/9 (0.0)	<0.001
Vascular injury, n (%)	70/87 (80.5)	31/44 (70.5)	30/34 (88.2)	9/9 (100)	0.047
LOS, days, mean (SD)	10.9 (18.7)	8.3 (11.5)	15.4 (26.3)	6.3 (5.0)	0.192
ICU LOS, days, mean (SD)	4.9 (3.9)	4.4 (3.4)	5.8 (4.7)	4.3 (1.5)	0.495
MESS, median (IQR)	3 (2)	4 (2)	3 (2)	3 (2)	0.534

ICU, intensive care unit; LOS, length of stay.

vascular hemorrhage controlled by the tourniquet. In nine of these cases, the limb was already partially or fully amputated at the scene, requiring a completion or revision amputation on arrival. In the other five, the amputation was required because of the severity of tissue damage from the injury. The remaining patient sustained a shotgun injury to the right elbow with a brachial artery transection and had a tourniquet applied in the ED of an outside hospital. This patient was transferred to our institution for definitive treatment. The arrival time was approximately 8 hours after tourniquet application. On admission to our ED, he was noted to have tense compartments and no sensation in his forearm or hand. He was immediately brought to the OR for exploration. Although the extent of injury to the limb was salvageable, all compartments were found to be devoid of viable muscle, and an amputation was performed. The tourniquet was lifesaving, and it is unknown if any residual flow to the arm existed before tourniquet placement; however, a contributory rule in the loss of this extremity could not be excluded.

Seven patients sustained 13 complications other than amputation including acute compartment syndrome (2.3%), acute renal failure (2.3%), bleeding (1.1%), coagulopathy (2.3%), adult respiratory distress syndrome (1.1%), hepatic failure (1.1%), shock (1.1%), and wound infection (2.3%). It is possible that the tourniquet contributed to the compartment syndrome, but as the patients in question had complete arterial transection with distal ischemia documented before tourniquet placement, direct attribution of this complication to the tourniquet is not possible. None of the other complications could be attributed to the use of a tourniquet.

TABLE 4. Operations

Limb Operations	Total Number (%)
Total operation, n	99
Irrigation and debridement, n (%)	14 (14.1)
Direct repair, n (%)	17 (17.2)
Vascular ligation, n (%)	35 (35.4)
Shunt, n (%)	4 (4.0)
Interposition graft, n (%)	12 (12.1)
Amputation, n (%)	6 (6.1)
Completion of amputation, n (%)	9 (9.1)
Reimplantation, n (%)	2 (2.0)

DISCUSSION

Despite the lack of any substantial civilian data regarding their use, tourniquets have become increasingly mainstream in North America. In a recent report from the American Association for the Surgery of Trauma Military Liaison Panel,[17] a case-based practice survey of primarily civilian surgeons examined several clinical issues including tourniquet use. For a patient with extremity trauma associated with external hemorrhage, 87% of the respondents felt that EMS providers should have tourniquets available for use. This increase in the civilian acceptance of tourniquet use has been in large part caused by the experience gained by combat casualty care providers[2–9] where tourniquets are a first-line option for the injured extremity. Unlike the available civilian data, the military evidence base is extensive. In the frequently cited work conducted by Kragh et al.,[4,5] two initial articles examined a cohort of 232 patients who had 428 tourniquets applied to 309 injured extremities. In this prospectively collected series of patients, early tourniquet use, before the onset of shock, was associated with improved survival, with no limb loss because of tourniquet use.[5] In the second publication using the same data set, complications were looked at specifically and found to be low, with no association between duration of use and morbidity.[4] In a continuation of this study, two further publications were produced surveying a total of 499 patients who had 862 tourniquets applied to 651 limbs, demonstrating findings consistent with their interim reports.[2,3] When the civilian literature is surveyed however, despite the fact that tourniquet use has become an accepted method of extremity hemorrhage control, there are very few reports available, consisting of only a handful of patients.[18,19] In the first series by Kalish et al.,[18] during a 7.5-year period, only 11 patients had tourniquets placed. Of these, six were placed for a gunshot wound, three for a stab wound, and two for a laceration. The mean (SD) tourniquet application time was

75 (38) minutes, and no neurologic complications were noted. In the other study by Passos et al.,[19] a comprehensive 10-year, two-center retrospective study yielded only eight patients who had tourniquets applied for arterial injuries, with only four of these in the prehospital phase of care. Tourniquet time and a detailed cataloging of limb-specific complications other than amputation were not available for analysis. Interestingly, all patients who had a prehospital tourniquet applied survived, and those who underwent amputation did so for the primary injury.

In this current data set, the largest in the civilian literature to date, 87 patients who had a tourniquet placed were examined in detail. The patient demographics were as expected, with penetrating injuries predominating in a younger patient population. Interestingly, more tourniquets were placed on the upper when compared with the lower extremities, and unlike the military data, it was rare for more than one tourniquet to be placed on a single extremity or for one patient to have concurrent multiple extremity injuries requiring tourniquet control. The CAT windlass type tourniquet is the product that is carried by most of our EMS agencies and is what is stocked in our ED. This is reflected in the predominance of this type of tourniquet in the prehospital and ED settings. In the OR however, all cases used a pneumatic system. Although the type of tourniquet used may impact efficacy,[20] in this study, availability dictated use. The use of improvised tourniquets, which have been demonstrated to be effective,[21] was uncommon and confined to the prehospital phase of care, before EMS arrival. In all cases, they were judged by the EMS provider to be adequate and were left in place until arrival in the ED where in only a third of cases was a CAT tourniquet substituted for the improvised device. If a major vascular injury is used as a surrogate marker of appropriateness of use, upwards of 80% were placed on patients with at least one named vascular injury. This did vary according to where the tourniquet was placed; however, even in the prehospital phase, 70% of patients had a named vascular injury. In the remainder, the most likely reason for tourniquet application would have been extensive soft tissue injury, which can bleed extensively. Analyzing the true appropriateness of use is difficult because in all of these cases, the tourniquet was placed for hemorrhage control, and whether a "true" named vascular injury was present, there had to have been external bleeding if the tourniquet was placed. Judging "overuse" is therefore difficult. Perhaps, more important is the examination of the complication rate as a marker of potential harm. In this study, a comprehensive review of outcomes was performed to identify tourniquet complications such as nerve damage, vascular thrombosis, local soft tissue damage, and myonecrosis attributable to the tourniquet use. Even with tourniquet times averaging 1 hour to 2 hours, the complication burden was low. The only complication directly attributed to the use of a tourniquet was a single amputation. Of the 15 amputations, 14 were caused by extensive destruction of the soft tissues and bone from the primary injury with many of the amputations occurring before tourniquet placement. For the last case however, although the shotgun injury to the upper extremity was destructive and there was an arterial injury with an element of distal ischemia, with an 8-hour tourniquet on time, it is possible that the duration of tourniquet use contributed at least in part to the need for amputation. Under these classic life-over-limb circumstances however, tourniquet use was still justified, with a net positive outcome.

From this uncontrolled, nonrandomized data set, it is not possible to provide meaningful data on the lifesaving impact of tourniquets or, conversely, the lives lost because a tourniquet was not applied. Because of the collateral military evidence base and low rate of complications associated with tourniquet use, it is unlikely that a randomized study will ever be performed to obtain these figures.

In summary, tourniquet use in the civilian sector is associated with a low rate of complications. Even in cases where prolonged use is required for transport, if the extremity injury is at risk of resulting in a hemorrhagic death, application with the potential for an increase in the need for amputation is justified.

CONCLUSION

Tourniquet use in the civilian sector is associated with a low complication rate and high potential for benefit, supporting the aggressive use of this potentially lifesaving intervention. Further work documenting differences in product design and optimal provider training are required.

AUTHORSHIP

K.I., S.S., S.R., and D.D. contributed in the study conception and design. S.R., J.Z., M.D.W., T.H., and S.S. performed the acquisition of data. T.H., S.S., and E.B. performed the analysis and interpretation of data. K.I., S.S., S.R., E.B., and D.D. drafted the manuscript. K.I., S.S., J.Z., M.D.W., T.H., E.B., and D.D. provided critical revision.

DISCLOSURE

The authors declare no conflicts of interest.

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