Prehospital tourniquet use in penetrating extremity trauma: Decreased blood transfusions and limb complications

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BACKGROUND: Despite increasing popularity of prehospital tourniquet use in civilians, few studies have evaluated the efficacy and safety of tourniquet use. Furthermore, previous studies in civilian populations have focused on blunt trauma patients. The objective of this study was to determine if prehospital tourniquet use in patients with major penetrating trauma is associated with differences in outcomes compared to a matched control group.

METHODS: An 8-year retrospective analysis of adult patients with penetrating major extremity trauma amenable to tourniquet use (major vascular trauma, traumatic amputation and near-amputation) was performed at a Level I trauma center. Patients with prehospital tourniquet placement (TQ) were identified and compared to a matched group of patients without tourniquets (N-TQ). Univariate analysis was used to compare outcomes in the groups.

RESULTS: A total of 204 patients were matched with 127 (62.3%) in the prehospital TQ group. No differences in patient demographics or injury severity existed between the two groups. Average time from tourniquet application to arrival in the emergency department (ED) was 22.5 ± 1.3 minutes. Patients in the TQ group had higher average systolic blood pressure on arrival in the ED (120 ± 2 vs. 112 ± 2, $p = 0.003$). The TQ group required less total PRBCs (2.0 ± 0.1 vs. 9.3 ± 0.6, $p < 0.001$) and FFP (1.4 ± 0.08 vs. 6.2 ± 0.4, $p < 0.001$). Tourniquets were not associated with nerve palsy ($p = 0.330$) or secondary infection ($p = 0.43$). Fasciotomy was significantly higher in the N-TQ group (12.6% vs. 31.4%, $p < 0.0001$) as was limb amputation (0.8% vs. 9.1%, $p = 0.005$).

CONCLUSION: This study demonstrated that prehospital tourniquets could be safely used to control bleeding in major extremity penetrating trauma with no increased risk of major complications. Prehospital tourniquet use was also associated with increased systolic blood pressure on arrival to the ED, decreased blood product utilization and decreased incidence of limb related complications, which may lead to improved long-term outcomes and increased survival in trauma patients. (*J Trauma Acute Care Surg.* 2019;86: 43–51.

LEVEL OF EVIDENCE: Therapeutic, level IV.
KEY WORDS: Tourniquet; extremity trauma; penetrating.

Military experience of tourniquet use for major limb trauma has been well described,[1] though tourniquets have only recently become widely adopted for civilian trauma. Over the last decade, the publication of several studies supporting the use of tourniquets in civilians ushered in a new era of domestic tourniquet use.[2–9] Several high profile mass causalities further popularized prehospital tourniquet application.[10,11] The Hartford Consensus published in 2014 solidified the role of tourniquets in the popular mindset and the commitment by the medical professional community to incorporate tourniquet usage into standard trauma paradigms.[12,13] As a result of the Hartford Consensus, the American College of Surgeons developed the Stop the Bleed course to teach nonmedical bystanders early hemorrhage control techniques, including tourniquet use, and to make bleeding control kits containing tourniquets more widely available to the lay public for use in bleeding emergencies.[14,15]

Despite increasing popularity of prehospital tourniquet use in civilians, relatively few studies to date have evaluated long-term tourniquet efficacy and safety compared with nontourniquet use in similarly injured patients. In addition, recent civilian studies have included large numbers of blunt trauma patients,[3,6,8] though results from previous military studies were largely conducted on patients with penetrating and/or blast injuries.[1,16,17] There has been some concern that evidence for tourniquet effectiveness gained in the military setting may not be directly extrapolate to civilian patients due to these differences in injury pattern and severity.[3,6] The lower Injury Severity Score (ISS) overall and high incidence of associated nonextremity-related blunt injuries have made drawing outcome conclusions related to tourniquet use in the civilian setting challenging. Few studies have effectively compared tourniquet patients to a control group of nontourniquet patients to assess outcomes. While a recent multicenter study demonstrated a mortality benefit to tourniquet placement,[18] there remains a paucity evidence describing the effect of tourniquets on shock prevention, blood product utilization, and incidence of secondary complications in civilian patients.[8,18]

The primary objective of this study was to determine if prehospital tourniquet use in patients with compressible bleeding from penetrating injuries is associated with differences in outcomes compared to a matched control group without tourniquet placement. Additional outcomes for patients with tourniquet placement in blunt trauma patients as well were also presented to add to the growing body of data for civilian tourniquet use.

METHODS

A single institution study was performed of consecutive trauma patients with extremity injuries and compressible bleeding arriving at University Medical Center in New Orleans, an American College of Surgeons accredited Level I trauma center, from 2010 to 2018. All patients with commercial tourniquet application for extremity injuries were identified from the trauma registry and from the New Orleans Emergency Medical Services (EMS) database. Patients who had tourniquet application for nontraumatic injuries (i.e., bleeding from arteriovenous fistula) or only had the placement of a noncommercial tourniquet device were excluded. Institutional review board approval was obtained from Tulane University, and research approval was obtained from University Medical Center in New Orleans prior to initiation of the study.

Patient demographics including: age, gender, race, mechanism of injury, ISS, and Abbreviated Injury Scale (AIS) score

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were recorded. Patients were stratified by mechanism (blunt vs. penetrating). Data related to tourniquet use, including what type of rescuer applied the tourniquet, length of tourniquet time to arrival in the emergency department (ED), and effectiveness of the tourniquet, were collected. The primary outcome was blood product utilization. Secondary outcomes included presence of shock on arrival, limb complications related to tourniquet use, systemic complications, hospital length of stay (LOS), intensive care unit (ICU) LOS, and in-hospital mortality. Major extremity injury was defined as injuries with major vascular injury (injuries to blood vessels requiring a procedural intervention to control bleeding), traumatic amputation, and/or near-amputation. Arrival to the ED in shock was defined as an initial systolic blood pressure (SBP) ≤ 90 mm Hg. Case-control matching was performed between patients with penetrating extremity injuries who had prehospital commercial tourniquets placed and patients who did not. The control group of patients had similar demographics, and ISS, with AIS score of the injured extremity as 2 or greater but did not have a commercial tourniquet placed at any point during the patient's management. These patients were located from the trauma registry during the study period. Clinical outcomes were compared between the two groups with the primary endpoint of blood transfusion. Secondary endpoints included limb complications, hospital LOS, and mortality.

Univariate analysis for statistical significance was performed using an unpaired two tailed Student's *t* test for continuous variables and Fisher's exact test or χ^2 test depending on sample size for categorical variables. Data were analyzed using GraphPad software (version 5, La Jolla, CA) and IBM SPSS (version 24, Armonk, NY). A p value of 0.05 or less was considered statistically significant.

RESULTS

Tourniquet Use Over Time

Commercial tourniquets were first introduced to prehospital providers in the New Orleans area in 2010. The combat application tourniquet was the most commonly used tourniquet. An analysis of trauma patients presenting to our Level I trauma center from 2010 to 2018 showed a steady increase in the frequency tourniquet application, from 2.2/1000 trauma activations in 2010 to 44.9/1000 trauma activations in 2018, despite a constant rate of traumatic extremity injury over that period (Fig. 1).

Tourniquet Patient Demographics

Table 1 describes the demographic and physiologic parameters for all tourniquet patients. A total of 238 patients had tourniquets placed for traumatic extremity injuries during the study period. The majority of patients were male gender and African American, with an average age of 34.5 years. Average ISS was 10.9 and average AIS score of the injured extremity was 2.2. Blunt trauma patients had a higher average ISS, higher average injured limb AIS score, and lower average Glasgow Coma Scale score than penetrating trauma patients. The average ISS of all patients with prehospital tourniquet placement showed a steady decrease over time, from 12.3 in 2010 to 11.6 in 2018. Average injured extremity AIS score trend was similar, decreasing from 3.0 in 2010 to 2.1 in 2018.

A large majority of tourniquets in this study were placed in patients with penetrating trauma (n = 176, 73.9%). Gunshot wounds were the most common type of penetrating trauma (46.0%), followed by sharp objects/glass (26.7%), knife/saw injuries (26.7%), and dog bites (0.6%). Blunt injuries accounted for 26.1% of injuries. The breakdown of blunt injuries was: motor vehicle/motorcycle collisions (50.0%), pedestrian versus vehicle (30.6%), crush injury (9.7%), fall (3.2%), bicycle versus vehicle (3.2%), and blast injury (3.2%).

Tourniquet Placement and Effectiveness

Table 2 details tourniquet placement and effectiveness. Most tourniquets were placed by paramedics or emergency medical technicians (68.5%), while firefighters and police officers placed 27.3%. While no commercial tourniquets were placed by lay bystanders, improvised tourniquets (i.e., belts, shirts, plastic bags) were used by bystanders in 13.9% of patients prior to placement of a commercial tourniquet device by trained rescuers. Patients with penetrating injuries were more likely to have tourniquets placed in the upper extremity, while blunt trauma patients were more likely to have tourniquets placed for lower extremity trauma. A total of 8.8% of patients had more than one tourniquet placed. Tourniquet application as evaluated by healthcare providers to effectively control hemorrhage control in the majority of patients (86.6%). The average time from EMS dispatch to placement of tourniquet was 10.9 minutes overall, though it was longer for patients with blunt injuries (15.3 minutes vs. 9.4 minutes, $p < 0.001$). Average time from tourniquet placement to arrival in the ED was 23.9 minutes (range, 0-150 minutes). There were nine patients who had tourniquets placed at the time of arrival to the ED. Average total time from EMS dispatch to hemorrhage control was 14.4 ± 0.9 minutes.

Injury Type and Complication Incidence

Table 3 shows injury patterns and outcomes for tourniquet patients. Patients with tourniquet placement for penetrating trauma were more likely to have a major vascular injury requiring operative intervention to control the bleeding, including both major arterial and venous injuries, while blunt trauma patients were more likely to have limb amputations, both traumatic and secondary, open fractures, and local wound infections. There

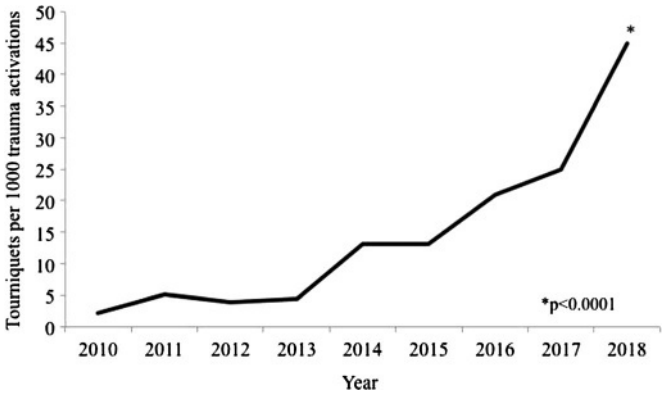

Figure 1. Trends in tourniquet use in a major urban city for patients presenting to a Level I trauma center as trauma activations. The number of patients with tourniquets for trauma increased from 2.2 of 1000 trauma activations to 44.9 of 1000 patients from 2010 to 2018, $p < 0.001$.

TABLE 1. Baseline Study Demographics and Physiologic Parameters for 238 Trauma Patients With Tourniquets From 2010 to 2018 Stratified by Mechanism

Parameter	All Patients (N = 238)	Penetrating (n = 176)	Blunt (n = 62)	*p*
Patient demographics				
Age, average (SEM)	34.5 (0.9)	32.9 (1.0)	39.2 (1.0)	0.002
Male sex, n (%)	207 (87.0)	155 (88.1)	52 (83.9)	0.39
White, n (%)	80 (33.6)	52 (29.5)	28 (45.2)	0.03
African American, n (%)	138 (58.0)	108 (61.4)	30 (48.4)	0.10
Other, n (%)	20 (8.4)	16 (9.1)	4 (6.5)	0.61
Injury information				
ISS, average (SEM)	10.9 (0.7)	8.4 (0.7)	17.4 (1.5)	<0.001
AIS score of extremity, average (SEM)	2.2 (0.1)	2.1 (0.1)	2.6 (0.1)	0.006
Prehospital vital signs				
SBP, average (SEM)	115 (2)	115 (3)	113 (5)	0.65
Heart rate, average (SEM)	99 (2)	98 (2)	101 (3)	0.49
Shock index, average (SEM)	0.9 (0.1)	0.9 (0.1)	1.0 (0.1)	0.20
Patient in shock, n (%)	54 (22.7)	36 (20.5)	18 (29.0)	0.22
Glasgow Coma Scale score, average (SEM)	13.3 (0.2)	13.7 (0.2)	12.0 (0.6)	<0.001
ED vital signs				
SBP, average (SEM)	117 (2)	119 (3)	119 (5)	0.28
Heart rate, average (SEM)	90 (2)	89 (2)	93 (4)	0.43
Shock index, average (SEM)	0.8 (0.02)	0.8 (0.03)	0.9 (0.1)	0.20
Patient in shock, n (%)	35 (14.7)	21 (11.9)	14 (22.6)	0.06
Glasgow Coma Scale score, average (SEM)	13.3 (0.2)	13.7 (0.2)	12.1 (0.6)	0.01

was no difference in fasciotomy rates or other complications including compartment syndrome, nerve palsy, deep vein thrombosis, or ischemia-reperfusion injury. Blunt trauma patients were more likely to require blood transfusions and had longer average ICU LOS and hospital LOS.

Comparison of Tourniquet Patients to Nontourniquet Patients

Patients with major extremity injury from penetrating mechanism who had prehospital tourniquets placed (TQ) were compared to matched patients without tourniquet placement (N-TQ). A total of 204 patients were compared, with 127 (62%) in the TQ group and 77 (38%) in the N-TQ group. Table 4 demonstrates that the study and control group were well-matched for patient demographics and injury severity. In the TQ group, average time from EMS dispatch to tourniquet application was 9.2 ± 0.6 minutes, and average time from tourniquet application to arrival in the ED was 22.5 ± 1.3 minutes, with 84.1% of patients achieving hemorrhage control with tourniquet application.

Clinical outcomes comparing the two cohorts are shown in Table 5. The TQ group required fewer transfusions of PRBCs (2.0 ± 0.1 units vs. 9.3 ± 0.6 units, $p < 0.001$) and FFP (1.4 ± 0.1 vs. 6.2 ± 0.4, $p < 0.001$). The TQ group had higher average SBP than the N-TQ group, both prehospital (114 ± 2 vs. 98 ± 4, $p < 0.001$)

TABLE 2. Application of Commercial Tourniquet Device for 238 Patients With Traumatic Injuries Stratified by Mechanism of Injury

Parameters	All Patients (N = 238)	Penetrating (n = 176)	Blunt (n = 62)	*p*
Tourniquet placement				
Paramedic/EMT, n (%)	164 (68.9)	118 (67.0)	46 (74.2)	0.34
Fire/police, n (%)	65 (27.3)	51 (29.0)	14 (22.6)	0.41
ED, n (%)	9 (3.8)	7 (4.0)	2 (3.2)	1.00
Improvised tourniquet placed before, n (%)	33 (13.9)	28 (15.9)	5 (8.1)	0.14
Location and efficacy of tourniquet				
Upper extremity, n (%)	124 (52.1)	102 (58.0)	22 (35.5)	0.003
Lower extremity, n (%)	115 (48.3)	75 (42.6)	40 (64.5)	0.003
Multiple tourniquets, n (%)	21 (8.8)	16 (9.1)	5 (8.1)	1.00
Bleeding controlled, n (%)	206 (86.6)	148 (84.1)	58 (93.5)	0.08
Tourniquet time				
Injury time to bleeding control, average minutes (SEM)	14.4 (0.9)	13.0 (0.8)	20.0 (2.4)	<0.001
EMS dispatch to tourniquet, average minutes (SEM)	10.8 (0.7)	9.2 (0.6)	15.5 (1.8)	<0.001
Tourniquet to ED arrival, average minutes (SEM)	24.0 (1.3)	22.5 (1.3)	26.6 (2.2)	0.23
Total tourniquet time, average minutes (SEM)	34.9 (1.5)	33.4 (1.7)	39.0 (3.2)	0.10

TABLE 3. Clinical Outcomes for 238 Patients With Tourniquets Placed

Parameter	All Patients (N = 238)	Penetrating (n = 176)	Blunt (n = 62)	*p*
Extremity injury				
Major vascular injury, n (%)	88 (37.0)	79 (44.9)	9 (14.5)	<0.001
Arterial injury, n (%)	75 (31.5)	68 (38.6)	7 (11.3)	<0.001
Venous injury, n (%)	30 (12.6)	27 (15.3)	3 (4.8)	0.04
Arterial and venous injury, n (%)	15 (6.3)	14 (8.0)	1 (1.6)	0.12
Traumatic amputation, n (%)	16 (6.7)	3 (1.7)	13 (21.0)	<0.001
Open fracture, n (%)	45 (18.9)	16 (9.1)	29 (46.8)	<0.001
Fasciotomy, n (%)	27 (11.3)	22 (12.5)	5 (8.1)	0.49
Procedure to control bleeding, n (%)	84 (35.3)	76 (43.2)	8 (12.9)	<0.001
Limb complications				
Secondary amputation, n (%)	6 (2.5)	1 (0.6)	5 (8.1)	0.005
Nerve palsy, n (%)	34 (14.3)	29 (16.5)	5 (8.1)	0.14
Local infection, n (%)	19 (8.0)	6 (3.4)	13 (21.0)	<0.001
Compartment syndrome, n (%)	14 (5.9)	12 (6.8)	2 (3.2)	0.53
Deep vein thrombosis, n (%)	8 (3.4)	5 (2.8)	3 (4.8)	0.43
Ischemia-reperfusion injury, n (%)	5 (2.1)	4 (2.3)	1 (1.6)	1.00
Outcomes				
Blood transfusion required, n (%)	97 (40.8)	61 (34.7)	36 (58.1)	0.002
Total PRBCs, average units (SEM)	2.2 (0.3)	2.0 (0.4)	2.5 (0.5)	0.50
Total FFPs, average units (SEM)	1.4 (0.3)	1.3 (0.3)	1.7 (0.7)	0.54
ICU LOS, average days (SEM)	1.7 (0.2)	1.2 (0.2)	3.2 (0.7)	<0.001
Hospital LOS, average days (SEM)	7.0 (0.6)	5.0 (0.5)	12.5 (1.8)	<0.001
Acute kidney injury, n (%)	10 (4.2)	5 (2.8)	5 (8.1)	0.13
In-hospital mortality, n (%)	21 (8.8)	12 (6.8)	9 (14.5)	0.07
Follow up length, average days (SEM)	200.5 (25.7)	176.0 (28.3)	268.6 (56.9)	0.11

and on arrival in the ED (120 ± 2 vs. 112 ± 2, $p = 0.003$), though there was no difference in HR or shock index ($p > 0.5$). While there was no difference in the incidence of prehospital shock between the two groups (23.6% vs. 24.7%, $p = 1.0$), patients with TQ placement had a trend toward lower incidence of shock on arrival to the ED than N-TQ patients (13.4% vs. 22.1%, $p = 0.120$). Hospital LOS was longer in N-TQ patients (5.1 ± 0.6 vs. 9.2 ± 1.2, $p = 0.001$), although in-hospital mortality did not differ statistically between the two groups. Tourniquets were not associated with a difference in nerve palsies or secondary infection rates. The N-TQ group had a significantly higher incidence of need for fasciotomy (12.6% vs. 31.4%, $p < 0.001$) and secondary amputation (0.8% vs. 9.1%, $p = 0.005$).

TABLE 4. Comparison of Demographics and Injury Patterns for Matched Patients With Penetrating Extremity Injuries With Compressible Bleeding Stratified by Prehospital Tourniquet Use

Parameters	Tourniquet (n = 127)	No Tourniquet (n = 77)	*p*
Patient demographics			
Age, years average (SEM)	31.3 (0.7)	31.2 (1.6)	0.95
Male sex, n (%)	111 (87.4)	68 (88.3)	1.00
White, n (%)	35 (27.6)	12 (15.6)	0.06
African American, n (%)	77 (60.6)	56 (72.7)	0.10
Other race, n (%)	15 (11.8)	9 (11.7)	1.00
Injury information			
ISS, average (SEM)	9.0 (0.5)	10.1 (0.6)	0.17
AIS score of injured limb, average (SEM)	2.8 (0.2)	2.7 (0.2)	1.00
Gunshot wound, n (%)	54 (42.5)	50 (64.9)	0.002
Knife/saw injury, n (%)	30 (23.6)	14 (18.2)	0.30
Sharp object/glass, n (%)	41 (32.3)	13 (16.9)	0.02
Animal bite, n (%)	2 (1.6)	0	0.53

DISCUSSION

Despite initial resistance due to concern for limb-related complications, tourniquets are being used with increasing frequency in the civilian population.[2–9] Widely publicized mass casualty events such as the Boston Marathon bombing and Pulse nightclub mass shooting have increased public interest in the use of tourniquets. Furthermore, widespread education of both medical and lay rescuers on achieving early hemorrhage control by tourniquet application through the "Stop the Bleed" campaign have increased the public awareness of tourniquet use for compressible extremity hemorrhage.[10–14] Our study demonstrated a steadily increasing rate since 2012 of tourniquet placement for compressible extremity hemorrhage, with 96% of patients with compressible extremity bleeding undergoing tourniquet placement in the prehospital setting. This phenomenon at our trauma center was likely due to the influence of one of the trauma surgeons, Dr. Norman McSwain, who was involved in the Hartford Consensus and instrumental in the introduction of tourniquets to prehospital providers. Other previous studies have reported much lower prehospital tourniquet application rates,

TABLE 5. Comparison of Clinical Outcomes for Matched Patients With Penetrating Extremity Injuries With Compressible Bleeding Stratified by Prehospital Tourniquet Use

Outcomes	Tourniquet (n = 127)	No Tourniquet (n = 77)	*p*
Prehospital vital signs			
SBP, average (SEM)	114 (2)	98 (4)	<0.001
Heart rate, average (SEM)	100 (2)	104 (5)	0.33
Shock index, average (SEM)	0.9 (0.1)	1.2 (0.1)	0.005
Patient in shock, n (%)	30 (23.6)	19 (24.7)	1.00
Vital signs on arrival in ED			
SBP, average (SEM)	120 (2)	112 (2)	0.003
Heart rate, average (SEM)	92 (3)	92 (4)	1.00
Shock index, average (SEM)	0.8 (0.1)	0.9 (0.1)	0.51
Patient in shock, n (%)	17 (13.4)	17 (22.1)	0.120
Limb complications			
Secondary amputation, n (%)	1 (0.8)	7 (9.1)	0.005
Nerve palsy, n (%)	8 (6.3)	2 (2.6)	0.33
Local infection, n (%)	3 (2.3)	4 (5.2)	0.43
Compartment syndrome, n (%)	9 (7.1)	5 (6.5)	1.00
Fasciotomy, n (%)	16 (7.8)	27 (35.0)	<0.001
Deep vein thrombosis, n (%)	4 (2.3)	7 (9.1)	0.11
Blood products			
PRBCs transfused, average units (SEM)	2.0 (0.1)	9.3 (0.6)	<0.001
FFPs transfused, average units (SEM)	1.4 (0.1)	6.2 (0.4)	<0.001
Other outcomes			
Procedure to control bleeding, n (%)	27 (51.9)	32 (61.5)	0.43
Hospital LOS, average days (SEM)	5.1 (0.6)	9.2 (1.2)	<0.001
In-hospital mortality, n (%)	9 (7.1)	10 (13.0)	0.21

ranging from 18% to 51%,[7,8,18] or rates which initially increased around 2011 or 2012 and then plateaued.[9,18] Our increasing incidence of prehospital tourniquet application likely reflects the growing trend of prehospital tourniquet placement across the nation, the strong educational focus that trauma and EMS providers in our region have placed on hemorrhage control and commercial tourniquet use by police/fire and lay rescuers, and a high incidence of patients with compressible extremity hemorrhage from penetrating injury. A case series published by Callaway and colleagues[19] was an early study to demonstrate that law enforcement officials could safely and successfully place tourniquets; we have confirmed this with the high number of prehospital tourniquets in our study population effectively placed by law enforcement officers and firefighters. While we started teaching Stop the Bleed in 2017 in our area, we did not find any documented instances of a civilian placing a commercial tourniquet device. However, with over 4,000 people trained on Stop the Bleed and distribution of commercial tourniquet devices to public buildings and schools, we anticipate that this will begin to occur in our area. We found that the average AIS score of patients with prehospital tourniquet placement decreased over time, from 3 in 2010 to 2.1 in 2018, reflecting in increasing frequency of tourniquet placement for less severe extremity injuries. This observation is certainly concerning that tourniquets are being used more liberally and eventually, the risks of frequent tourniquet placement might outweigh potential benefits. This study demonstrates that so far prehospital tourniquet placement has not been associated with increased risk of limb complications, likely due to relatively short urban transport times on average, we did have several patients transported from rural areas with tourniquet times >120 minutes with no documented complications related to the tourniquet. At present, we are continuing to collect outcomes associated with prehospital tourniquet use in our patients to ensure safety and quality care.

Kragh et al's landmark article was one of the first modern studies to provide incontrovertible evidence supporting tourniquet use in the battlefield.[1] A total of 428 tourniquets were applied to a predominantly penetrating trauma population, and the authors found that tourniquet use when shock was absent was strongly associated with survival (90% vs. 10%, $p < 0.001$). Several studies over the past few years have sought to translate military data for domestic use to elucidate the role of tourniquet use for civilian extremity trauma, but it has not been without challenges. While tourniquets have been proven on the battlefield for penetrating and blast injuries, most civilian studies have been comprised largely of blunt trauma patients, ranging from 33% to greater than 70% blunt mechanism. These patients present a unique challenge, since on average they have higher injury severity due to non–limb-related injuries which can act as confounding variables to impact outcomes intended to measure tourniquet effectiveness such as arrival in shock, blood product utilization, morbidity and mortality. We confirmed this with our study population, which showed that in blunt patients who had tourniquets placed for extremity trauma the average ISS was significantly higher, suggesting that these patients likely had complex blunt trauma. We found that these patients had a significantly higher incidence of traumatic and secondary limb amputation as well as local limb infection. This observation is interesting, as previous studies have not stratified limb complications specifically by mechanism. Likely, the patients with blunt trauma had more devastating injuries with more extensive soft tissue destruction or severe fractures that would ultimately require amputation.

Our study population has the highest reported percentage of penetrating extremity trauma patients to date at 74%, and describes key differences in injury pattern and severity between blunt and penetrating trauma patients which may affect future research. We found that the penetrating trauma patients were more likely to have major vascular injury and to require operative procedure for hemorrhage control. For these reasons, we decided to focus our comparative analysis evaluating tourniquet outcomes specifically to our patients with penetrating mechanism of injury.

Until recently, most civilian tourniquet studies have been largely descriptive but have lacked a comparison control group to adequately analyze outcomes. In 2017, Scerbo and colleagues[8] published the largest study to date of 306 patients who required tourniquet placement showing that patients who had tourniquets placed in a prehospital setting compared to after trauma center arrival had decreased blood transfusions within the first hour and decreased mortality from hemorrhagic shock. However, these patients were mostly blunt trauma (70%), and data specific to limb outcomes were not specifically addressed. More recently, Teixiera and colleagues[18] published a multi-institutional study describing

1026 patients with peripheral vascular injuries. They found that on multivariate analysis, prehospital tourniquet placement was independently associated with increased survival. They also described a dramatically variable prehospital tourniquet placement rate between hospitals with an overall average of less than 18%, and the tourniquet patients were more likely to require massive transfusion protocol, have a higher ISS and AIS score, and to have presence of shock. While no difference was found in delayed amputation rates, they did not compare rates of other complications such as secondary infection, nerve palsy, fasciotomy, or compartment syndrome.

We believe that our study compliments these two recent studies of the civilian tourniquet use in several ways. It has the highest rate of patients with extremity hemorrhage due to penetrating injury and is the only study to specifically focus on outcomes in this subset of patients without the confounding effects of blunt multisystem injuries on outcomes analysis. We found that prehospital tourniquet placement was associated with reversal of the incidence of shock, with 24% of patients in shock at the time of prehospital tourniquet application and only 13.4% still in shock by ED arrival. In contrast, the incidence of nontourniquet patients in shock at the time of ED arrival did not change from the prehospital setting. Despite a somewhat different patient population, our findings mirrored those of Scerbo and colleagues that prehospital tourniquet use is associated with decreased blood product utilization and increased arrival SBP. However, we did not see a significant difference in mortality, possibly due to somewhat smaller study size.

Interestingly, though limb complications such as nerve palsy and ischemic injury causing secondary amputation have been traditionally cited as concerning potential complications from tourniquet use, our matched analysis of all TQ versus N-TQ patients found that limb complications including secondary amputation and fasciotomy rates were actually higher in the N-TQ group. We found no difference nerve palsy rates, and upon further review of all TQ patients' charts, it was determined that all nerve palsies were at the level of the injury rather than the level of the tourniquet and therefore were not directly attributable to tourniquet use.

This study is limited by its retrospective design, especially due to the resultant difficulty in gathering certain data points, most notably from the prehospital setting. Some data points, such as efficacy of hemorrhage control, are inherently subjective in nature and may be affected by observer bias. The decision to place a tourniquet was completely at the discretion of prehospital providers and while we attempted to adjust for potential confounding factors by matching the control group, the study may still have some selection bias. The control group was selected from largely historical controls due to more recent widespread use of tourniquets for penetrating trauma patients. This effectively limited the sample size for the control group due to missing data from the larger cohort for our controls in the first few years of our study. While our trauma system has not made significant changes to our massive transfusion protocols or other management practices for patients with penetrating extremity hemorrhage over the study period, we acknowledge that this is also a potential weakness of the study as changes in outcomes over time might have biased our results. Furthermore, the results presented are from a single institution. The trauma center in this study has a high percentage of penetrating trauma, which is above the national average for most Level I trauma centers. While these data may be of interest to other urban Level I trauma centers with high rates of penetrating injury, broad applicability of our results to more rural trauma centers or those with a lower incidence of penetrating trauma may be limited.

CONCLUSION

Our study demonstrates that prehospital tourniquets can be safely used to control bleeding in compressible penetrating extremity hemorrhage and are associated with decreased blood product utilization without increased risk of major tourniquet-related limb complications. Our study also suggests that the indications and results for patients with tourniquet placement vary significantly based upon the mechanism of injury; patients with penetrating injuries tended to have major vascular trauma requiring operative hemorrhage control, while patients with blunt injuries tended to be more severely injured and had open fractures, amputations and nonextremity related injuries. Prehospital tourniquet placement for penetrating extremity hemorrhage effectively provided temporary hemorrhage control until definitive interventions could be performed, which may lead to improved long-term outcomes and increased survival in trauma patients.

AUTHORSHIP

A.A.S. participated in the study design, data collection, data analysis, and writing/editing of the article. J.O. participated in the study design and data collection. S.W. participated in the study design and data collection. S.B. participated in the study design and data collection. J.E. participated in the data collection, data analysis, and writing of the article. C.G. participated in the data analysis and writing/editing of the article. P.MG. participated in the data analysis and writing/editing of the article. C.MG. participated in the writing/editing of the article. J.D. participated in the writing/editing of the article. R.S. participated in the study design, data collection, data analysis, and writing/editing of the article.

DISCLOSURE

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DISCUSSION

Joseph J. DuBose, MD (Baltimore, Maryland): I would like to thank Dr. Croce, Dr. Winchell, and the Association for the honor of reviewing this paper. It was truly an honor and a pleasure to have the opportunity to review the work by the Tulane group.

Their fantastic effort does much to add to a growing body of literature that is further dispelling archaic notions that prehospital tourniquet use in appropriately selected trauma patients represents a prohibitive danger.

As the authors clearly illustrate in their present work, when effectively employed in the context of a mature EMS system that is supported by a leading academic trauma center, tourniquets prevent morbidity and have the potential to save lives.

In reading their work, I could not help but sense the influence of a hero and a friend to many in the room, Dr. Norman McSwain. His lifelong advocacy for improvement in pre-hospital outcomes and EMS services reached far beyond the Crescent City.

I know that he is somewhere smiling in that iconic turtleneck and bolo tie at the manner in which this torch is being carried forward by his mentees and friends. I have only a few questions for Alison and my friends from New Orleans.

First, the DoD spent millions of dollars in rigorous testing on a variety of tourniquets, before ultimately settling on the combat application, or CAT, tourniquet.

This device is now utilized in teaching in the Stop the Bleed program, yet a variety of other commercial devices exist and have been adopted by some EMS services. Do you have any data on how many of your tourniquets were actually CATs?

Second, I note that, of the 204 patients with penetrating extremity injury, an impressive 62 percent had a tourniquet placed. My own observations with maintenance of the AAST Multi-Center Prospective Observational Vascular Injury Treatment, or PROOVIT, Registry suggests that this is likely much higher than is seen nationally, even among some of the major urban trauma centers that contribute to PROOVIT.

What is your secret to promoting a higher rate for penetrating indications? You speak of the value of the EMS education, but does Tulane also have a role in setting the protocols for EMS services in the region? Do delivering EMS services then uniformly incorporate tourniquet use into their algorithms?

And finally, very briefly, you very nicely note that tourniquet use by EMS services increased over the time of your study population, and you mentioned the benefit of the Stop the Bleed program, but how specifically did these benefits relate to your introduction to the program in your area?

I congratulate the group from New Orleans on an excellent contribution, and I look forward to your answers.

Anna M. Ledgerwood, MD (Detroit, Michigan): Nice presentation. How many patients did not need the tourniquet? During this time, did you have any patients who did need the tourniquet that didn't get one?

Marc A. DeMoya, MD (Milwaukee, Wisconsin): The number of tourniquets certainly increased dramatically, actually, over the last several years. And you stipulate that the number of blood transfusions and potential complications had decreased.

My question is, what surrogate marker did you use to determine if those tourniquets actually needed to be applied? According to your table there was no difference in number of operations, so how do you know that you're not putting on a lot more unnecessary tourniquets? Thank you.

Erik Streib, MD (Indianapolis, Indiana): I'm wondering if tourniquets are going to have some of the same problems that we see with cervical collars, in that they're becoming widely accepted and applied more and more by lay people and public safety employees without the certain knowledge of an injury.

And I'll echo the same question. Do we know, of the total number, how many people turned out not to have a serious injury, although there clearly is benefit to those that do?

My question is, do you have criteria or a protocol for the examination of the limb with the tourniquet, including criteria for removal of the tourniquet?

Zachary Brown, DO (Camp Lejeune, North Carolina): A question regarding who is applying the tourniquets, whether it was EMS firefighters versus civilians.

Did you note at all the proportion that were applied correctly by either group, and what the breakdown was as far as mortality, also, between those two different groups?

Babak Sarani, MD (Washington, D.C.): Two very quick questions. You mentioned that the tourniquet time was defined as time of application to patient arrival in the Emergency Department, which makes me wonder, if the tourniquets were taken down in the ED, how many of them were actually necessary?

And secondly, you reported that 76 patients required some form of operative exploration. It would be very easy to answer

all of our questions by looking at those 76 patients, and seeing how many of them actually had an injury to a main vessel, arterial or venous, that would have necessitated tourniquet control. The probably of a main vessel injury following a gunshot wound in the extremities is actually quite low.

Adam Fox, DO (Newark, New Jersey): While you focused on the commercial tourniquets, I noticed that you did have a little blurb about homemade tourniquets there. Were you able to tease out any more information about whether those homemade tourniquets were effective? And along the same lines as some of the other questions, were they needed?

Alison A. Smith, MD, PhD (New Orleans, Louisiana): I would like to thank Dr. DuBose for all of his expertise and for giving us timely feedback on our manuscript. I would also like to thank everybody in the audience for their questions.

To address Dr. DuBose's first question, the majority of patients in our study had CAT tourniquets. This type of tourniquet was initially available to New Orleans EMS.

There were a few other EMS companies in New Orleans that used different types of tourniquets but they all have since switched to CATs. The majority of the EMS reports we reviewed for our study did indicate what type of tourniquet was placed, and we confirmed that they were indeed CAT tourniquets.

In terms of the observation regarding the high amount of tourniquets placed in the New Orleans area for penetrating trauma, what Dr. DuBose eluded to regarding the influence and role of Dr. McSwain is true.

Dr. McSwain was the driving force behind starting to use tourniquets in New Orleans and in many other cities across the world. He helped to write the initial EMS protocols for the use of tourniquets by New Orleans EMS.

And since Dr. McSwain's death, one of our co-authors, Dr. Jeffrey Elder, who is an Emergency Medicine physician and former medical director of New Orleans EMS, helped to fill some of that role that Dr. McSwain left behind. In particular, Dr. Elder has helped to continue the education of our pre-hospital providers.

In terms of additional teaching of pre-hospital providers, Dr. McSwain started a national symposium for EMS providers that still continues annually. Trauma surgeons from Tulane and LSU are involved in helping to educate pre-hospital providers during that conference every year.

To address the final question regarding Stop the Bleed training, this program was started in the New Orleans area in 2017. The senior author for this paper, Dr. Rebecca Schroll, brought this program to the New Orleans area. Since the program started about a year and a half ago, we have trained about 4,000 medical providers and lay rescuers.

The lay rescuers trained have largely been teachers, and there is also a push to bring Stop the Bleed kits and commercial tourniquets to our local schools.

So, while we did not observe any civilians placing a commercial tourniquet device in our study, we anticipate that over the next year or so, we will start to see civilians placing these commercial tourniquet devices as they become more widely available.

Now, to address some of the other questions asked. Regarding Dr. Ledgerwood's question in terms of how many of these patients did need a tourniquet, all of the EMS reports at the time of tourniquet placement indicated that the medic, firefighter, or policeman was worried about bleeding, specifically arterial bleeding, so the pre-hospital providers felt justified when they placed the tourniquet.

We did look at some of the injuries when the tourniquet was taken down in the ED to determine if a major vessel was injured, and we're trying to collect more data on what percentage of major vascular structures were involved.

But we would argue that if the emergency medical providers in these situations think the injury is an arterial bleed and also knowing that our study demonstrated that tourniquets did not have a significant amount of long-term consequences in regards to limb complications, then they should feel clinically justified to place the tourniquet. The ramifications for the affected limb probably are not going to be significant even if tourniquet placement ultimately was not for a major blood vessel injury.

Furthermore, we have quick transport times by EMS and the patients were able to get the tourniquet evaluated by a physician in the emergency room on average within 30 minutes.

Also, for Dr. deMoya's questions, we are looking into the operative repairs for these patients to determine how many patients had arterial injuries and needed some type of procedure that was specifically related to an injured blood vessel.

We did observe that over the study period, within the last year or so, more tourniquets were placed for patients with AIS 1, so the number of tourniquets that are being placed in our region continues to increase.

But again, these patients didn't have any substantial long-term consequences from tourniquet placement. However, it is something to be mindful of, that there might be an "overuse" of tourniquets within the next few years. We plan to continue to evaluate this phenomenon to determine if this is going to have significant long-term consequences for our patient population.

