

Effect of prehospital tourniquets on resuscitation in extremity arterial trauma

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ABSTRACT

Background Timely tourniquet placement may limit ongoing hemorrhage and reduce the need for blood products. This study evaluates if prehospital tourniquet application altered the initial transfusion needs in arterial injuries when compared with a non-tourniquet control group.

Methods Extremity arterial injuries were queried from our level I trauma center registry from 2013 to 2017. The characteristics of the cohort with prehospital tourniquet placement (TQ+) were described in terms of tourniquet use, duration, and frequency over time. These cases were matched 1:1 by the artery injured, demographics, Injury Severity Score, and mechanism of injury to patients arriving without a tourniquet (TQ-). The primary outcome was transfusion within the first 24 hours, with secondary outcomes of morbidity (rhabdomyolysis, renal failure, compartment syndrome), amputation (initial vs. delayed), and length of stay. Statistical tests included t-test and χ^2 for continuous and categorical variables, respectively, with $p < 0.05$ considered as significant.

Results Extremity arterial injuries occurred in 192 patients, with 69 (36%) having prehospital tourniquet placement for an average of 78 minutes. Tourniquet use increased over time from 9% (2013) to 62% (2017). TQ+ patients were predominantly male (81%), with a mean age of 35.0 years. Forty-six (67%) received blood transfusion within the first 24 hours. In the matched comparison ($n=69$ pairs), TQ+ patients had higher initial heart rate (110 vs. 100, $p=0.02$), frequency of transfusion (67% vs. 48%, $p<0.01$), and initial amputations (23% vs. 6%, $p<0.01$). TQ+ patients had increased frequency of initial amputation regardless of upper ($n=43$ pairs) versus lower ($n=26$ pairs) extremity involvement; however, only upper extremity TQ+ patients had increased transfusion frequency and volume. No difference was observed in morbidity, length of stay, and mortality with tourniquet use.

Discussion Tourniquet use has increased over time in patients with extremity arterial injuries. Patients having prehospital tourniquets required a higher frequency of transfusion and initial amputation, without an increase in complications.

Level of evidence Therapeutic study, level IV.

BACKGROUND

Uncontrolled bleeding is recognized as a cause of potentially preventable mortality in trauma patients. Tourniquets are effective in controlling hemorrhage from severe extremity injuries. Military reviews have demonstrated improved survival in injuries amenable to tourniquets, especially if

placed in the field and prior to the onset of shock.^{1,2} The translation of these results to civilian experience remains a debated topic due to differences in transport times, mechanism of injury, and patient demographics. Recently, several retrospective series have demonstrated effective and appropriate tourniquet use in American trauma systems.³⁻⁵

Our urban trauma center treats a high volume of both blunt and penetrating extremity injuries that allowed characterization of civilian tourniquet experience. We describe our cohort of patients with extremity arterial injuries with prehospital tourniquet placement and compare with a matched cohort with similar injuries but without tourniquet placement.

METHODS

Patients were identified by the International Classification of Diseases codes for arterial injury and amputation at our level I trauma center registry. Time period of the study was 5 years, from January 2013 through December 2017. Patients without a documented arterial injury were excluded.

Demographics included age, gender, mechanism of injury, Injury Severity Score (ISS), extremity Abbreviated Injury Score, Mangled Extremity Severity Score (MESS), and concurrent injuries. Resuscitation variables were initial vital signs, initial Glasgow Coma Scale score, admission hematocrit, duration of tourniquet application, surgical interventions performed, and transfusion requirement within the first 24 hours. Blood products measured included packed red blood cells (pRBCs) and fresh frozen plasma (FFP). Amputations were classified as initial (performed at first operation) or delayed (performed at a later procedure).

Patients with a prehospital tourniquet (TQ+) were matched to patients without tourniquet placement (TQ-) in a 1:1 manner based on demographics, injured artery, ISS, and mechanism. The primary outcome of interest for the case-control comparison was blood transfusions within the first 24 hours. Secondary outcomes included hospital-free days, intensive care unit (ICU)-free, and ventilator-free days (30-day benchmark), presence of significant complications including acute kidney injury, rhabdomyolysis (defined as creatine kinase >5000), compartment syndrome, limb loss, and mortality. Statistical analysis was performed with Stata V.14. Descriptive variables are reported as number of patients and percentage of cohort. Continuous variables are reported as mean and SEM, with ranges when appropriate. Normally

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**Table 1** Injury characteristics of patients with tourniquets

Parameter	TQ+ (n=69)
Tourniquet duration, mean (SEM), minutes	78 (6)
Arterial involvement	
Brachial, n (%)	20 (29)
Radial/Ulnar, n (%)	23 (33)
Femoral, n (%)	6 (9)
Popliteal, n (%)	10 (14)
Tibial/Peroneal, n (%)	10 (14)
Concurrent vein injury, n (%)	35 (51)
Operative intervention	
Arterial repair, n (%)	35 (51)
Arterial ligation, n (%)	18 (26)
Venous repair, n (%)	5 (7)
Initial amputation, n (%)	16 (23)
Fracture fixation, n (%)	19 (28)
Fasciotomy, n (%)	14 (20)
Exploratory laparotomy, n (%)	3 (4)

TQ+, with prehospital tourniquet.

distributed variables were compared using Student's t-test, with χ^2 or Fisher's exact test for categorical comparisons. Significance was set at a p value of less than 0.05.

RESULTS

Extremity arterial injuries occurred in 192 patients during the study period, with 69 (36%) having prehospital tourniquet placement. Seven additional patients with tourniquet placement after trauma center arrival were excluded. Tourniquet utilization increased throughout the study period from 9% in 2013 to 62% in 2017 ($p < 0.01$). Tourniquets were more frequent in the upper extremity than the lower extremity (43% vs. 28%, $p = 0.03$).

Characteristics and outcomes of tourniquet patients

Patients receiving tourniquets were predominantly male (56 patients, 81%), with a mean age of 35.0 years (range 17–68). The average tourniquet duration was 78 minutes (range 15–260). The mechanism of injury for the TQ+ patients included penetrating trauma in 40 (58%) and blunt trauma in the remaining 29 (42%). Arterial involvement and operative intervention for TQ+ patients are summarized in [table 1](#). Forty-six (67%) individuals required blood transfusion within the first 24 hours. The average transfusion was 3.5 units of pRBCs (range 0–22) and 2.4 units of FFP (range 0–18). No patient arriving with a tourniquet died. Morbidity included rhabdomyolysis in 15 (22%), compartment syndrome in 1 (1%), and acute kidney injury in 4 patients (6%). TQ+ patients averaged 25.8 ICU-free days (range 0–27), 27.7 ventilator-free days (range 0–30), and 17.4 hospital-free days (range 0–29).

Case-control comparison of tourniquet and non-tourniquet patients

Patients arriving with an extremity arterial injury and prehospital tourniquet were then matched to a cohort without a tourniquet placement (TQ–). [Table 2](#) demonstrates that the groups were well matched in demographics, severity, and mechanism.

The clinical outcomes of TQ+ patients compared with TQ– patients those without are presented in [table 3](#). TQ+ patients arrived with a higher heart rate (110 vs. 100, $p = 0.02$) and MESS

Table 2 Demographics and mechanism of injury for case-control match

Demographics	TQ+ (n=69)	TQ– (n=69)	P value
Age, mean (SEM), years	35.0 (1.5)	36.3 (1.6)	NS
Male gender, n (%)	56 (81)	53 (77)	NS
ISS, mean (SEM)	13.1 (0.8)	12.3 (0.9)	NS
Extremity AIS, mean (SEM)	3.2 (0.1)	3.0 (0.1)	NS
Mechanism of injury			
Gunshot wounds, n (%)	10 (14)	15 (22)	NS
Knife wounds/stabbing, n (%)	12 (17)	11 (16)	
Glass/saw/other penetrating, n (%)	17 (25)	10 (14)	
Bite, n (%)	1 (1)	2 (3)	
Motor vehicle collision, n (%)	11 (16)	9 (13)	
Motorcycle/All-terrain vehicles, n (%)	12 (17)	15 (22)	
Pedestrian/Fall, n (%)	6 (9)	7 (10)	

AIS, Abbreviated Injury Score; ISS, Injury Severity Score; NS, not significant; TQ–, without tourniquet placement; TQ+, with prehospital tourniquet.

score (5.8 vs. 5.1, $p = 0.03$). Transfusion frequency was higher in TQ+ patients (67% vs. 48%, $p = 0.03$); however, the number of units was not different. TQ+ patients underwent more initial amputations (23% vs. 6%, $p < 0.01$), but similar frequency of delayed amputation. The rates of morbidity, mortality, and length of stay were not different.

Given the potential severity of injury necessitating an initial amputation, the case-control cohort was then re-evaluated with these patients excluded ($n = 16$ pairs removed). The demographics, severity, and mechanism remained adequately matched. No difference was observed in MESS by tourniquet use (4.9 vs. 4.7, $p =$ not significant). TQ+ patients continued to have a statistically significant higher heart rate (111 vs. 99, $p = 0.02$) and required more units of pRBCs (3.3 vs. 1.8, $p = 0.03$) and FFP (2.2 vs. 0.9, $p = 0.02$) compared with their matched TQ– controls

Table 3 Comparison of clinical outcomes with and without tourniquet placement

	TQ+ (n=69)	TQ– (n=69)	P value
HR, mean (SEM), bpm	110 (4)	100 (3)	0.02
SBP, mean (SEM), mm Hg	126 (4)	130 (3)	NS
Hematocrit, mean (SEM), %	37.0 (0.9)	37.8 (0.6)	NS
MESS, mean (SEM)	5.8 (0.3)	5.1 (0.3)	0.03
Received transfusion in the first 24 hours, n (%)	46 (67)	33 (48)	0.03
pRBCs, mean (SEM), units	3.5 (0.5)	2.7 (0.8)	NS
Initial amputation, n (%)	16 (23)	4 (6)	<0.01
Delayed amputation, n (%)	6 (9)	7 (10)	NS
Rhabdomyolysis, n (%)	15 (22)	12 (17)	NS
Compartment syndrome, n (%)	1 (1)	2 (3)	NS
Acute kidney injury, n (%)	4 (6)	2 (3)	NS
Ventilator-free days, mean (SEM), 30 days	27.7 (0.6)	28.3 (0.6)	NS
ICU-free days, mean (SEM), 30 days	25.8 (0.7)	26.7 (0.6)	NS
Hospital-free days, mean (SEM), 30 days	17.4 (1.2)	20.1 (1.0)	NS
Death, n (%)	0 (0)	2 (3)	NS

HR, heart rate; ICU, intensive care unit; MESS, Mangled Extremity Severity Score; NS, not significant; SBP, systolic blood pressure; TQ+, with prehospital tourniquet; TQ–, without tourniquet placement; bpm, beats per minute; pRBCs, packed red blood cells.

Table 4 Clinical outcomes in matched pairs excluding initial amputations

	TQ+ (n=53)	TQ- (n=53)	P value
HR, mean (SEM), bpm	111 (4)	99 (3)	0.02
SBP, mean (SEM), mm Hg	123 (5)	131 (3)	NS
Hematocrit, mean (SEM), %	37.5 (0.9)	38.1 (0.7)	NS
Received transfusion in the first 24 hours, n (%)	33 (62)	25 (47)	NS
pRBCs, mean (SEM), units	3.3 (0.6)	1.8 (0.4)	0.03
FFP, mean (SEM), units	2.2 (0.5)	0.9 (0.3)	0.02
Delayed amputation, n (%)	6 (11)	3 (6)	NS

FFP, fresh frozen plasma; bpm, beats per minute; HR, heart rate; NS, not significant; pRBCs, packed red blood cells. SBP, systolic blood pressure; TQ+, with prehospital tourniquet; TQ-, without tourniquet placement;

(table 4). No differences were observed in delayed amputation, morbidity, mortality, and length of stay.

The case-control cohort was then stratified into upper (n=43) and lower (n=26) extremity injury pairs. The demographics, severity, and mechanism remained adequately matched. Increased frequency of initial amputation in TQ+ patients continued to be statistically significant for both upper (12% vs. 0%, p=0.02) and lower (42% vs. 15%, p=0.03) extremities (table 5). However, only TQ+ upper extremities had increased heart rate (112 vs. 100, p=0.01) and frequency and volume of transfusions. No differences were observed in delayed amputation, morbidity, mortality, and length of stay.

DISCUSSION

Hemorrhage is a cause of potentially preventable mortality in trauma patients that can be reduced through the use of tourniquets. The American College of Surgeons Committee on Trauma and the Hartford Consensus advocate for tourniquet use and standardization of training through the Stop the Bleed Initiative.^{6,7} Despite the enthusiasm, tourniquets are uncommon in civilian experience, with an estimated incidence of 0.2 per 1000 emergency medical service (EMS) activations.⁸ As Kauvar *et al*⁹ point out in their review, civilian literature is heterogeneous, with great variability in cohort composition, data collection, and outcomes measured. Despite the lack of high-quality research,

current studies suggest that tourniquets are being employed safely and effectively, despite a lack of nationwide protocols.¹⁰ Scerbo *et al*³ found 90% indicated use, without complication directly attributable to tourniquet use.³ In a rural cohort, there was 98% hemorrhage control in 61 patients having commercial tourniquet placement.⁴ A multicenter study demonstrated 88% effectiveness in prehospital tourniquet application with significantly lower mortality and amputation rates than in American military experience.⁵

Of particular interest was whether tourniquet use altered the initial (first 24 hours) transfusion requirement. Timely tourniquet placement may limit ongoing hemorrhage and reduce the need for, or volume of, blood products. Patients with delayed or missed opportunity for tourniquets are observed to have an increased incidence of shock and blood transfusions.¹¹ In a small Canadian cohort, those patients with extremity exsanguination leading to death were transfused with more blood products than those with early tourniquets.¹² The observed average transfusion of 3.5 units of pRBCs is similar to current published literature.^{5,13} Comparatively, more of our patients with field tourniquets required transfusion, a difference that persisted even when those undergoing primary amputation were excluded.

A previous study had observed no difference in frequency or volume of transfusion by timing of tourniquet placement (prehospital vs. emergency room vs. operating room).¹³ Interestingly,

Table 5 Clinical outcomes stratified by upper and lower extremity

Upper extremity	TQ+ (n=43)	TQ- (n=43)	P value
HR, mean (SEM), bpm	112 (4)	100 (3)	0.01
SBP, mean (SEM), mm Hg	130 (5)	130 (3)	NS
Hematocrit, mean (SEM), %	37.3 (1.1)	37.2 (0.8)	NS
Received transfusion in the first 24 hours, n (%)	26 (60)	17 (40)	0.05
pRBCs, mean (SEM), units	2.3 (0.4)	1.3 (0.3)	0.04
FFP, mean (SEM), units	1.2 (0.3)	0.5 (0.2)	0.03
Initial amputation, n (%)	5 (12)	0 (0)	0.02
Lower extremity	TQ+ (n=26)	TQ- (n=26)	P value
HR, mean (SEM), bpm	106 (8)	101 (5)	NS
SBP, mean (SEM), mm Hg	120 (7)	132 (5)	NS
Hematocrit, mean (SEM), %	36.5 (1.6)	38.7 (1.0)	NS
Received transfusion in the first 24 hours, n (%)	16 (62)	20 (77)	NS
pRBCs, mean (SEM), units	5.5 (1.0)	5 (2.0)	NS
FFP, mean (SEM), units	4.3 (0.9)	3.4 (1.5)	NS
Initial amputation, n (%)	11 (42)	4 (15)	0.03

FFP, fresh frozen plasma; bpm, beats per minute; HR, heart rate; NS, not significant; pRBCs, packed red blood cells. SBP, systolic blood pressure; TQ-, without tourniquet placement; TQ+, with prehospital tourniquet;



our results contrast a recent study that found a significantly decreased blood product requirement in patients receiving a tourniquet for penetrating extremity trauma.¹⁴ The study period was prior to the implementation of thromboelastography (TEG) at the institution; thus, resuscitation and transfusion were at the discretion of the trauma surgeon, with intent for a 1:1 ratio.

Tourniquet duration in this cohort ranged from 15 minutes to over 4 hours, reflecting the large geographic catchment area of this trauma center (over 10 000 square miles). Short transport and tourniquet times were noted for injuries within the city limits, with long tourniquet duration for patients transferred, often via helicopter, from outlying regions. The mean duration of over 1 hour was comparable with several published series,^{11 13} although longer than other series both urban and rural.^{4 14}

Opponents of widespread tourniquet use cite potential morbidity as a significant concern. A high frequency of amputations and fasciotomies with low rates of myonecrosis and acute renal failure are reported from military experience.¹⁵ Civilian populations, overall, appear to have lower rates of rhabdomyolysis, renal failure, and amputations.^{4 5} Indeed, the rates of acute kidney injury and compartment syndrome in this group are similar to other civilian reports.^{3 13} Strikingly, patients with tourniquets underwent more initial amputations (23% of all tourniquets; 42% of lower extremity tourniquets) than those without tourniquets. Kragh *et al*'s military cohort had a 35% amputation rate, with several civilian series having a frequency of 17% to 29%.^{3 5 13 15} Analysis of the etiology of amputation in one series was evenly divided between traumatic amputation and non-salvageable limbs.³ Likewise, we theorize that injury severity was critical in the decision to amputate than the presence of a tourniquet. A significant number of the initial amputations had mangled, nearly amputated arms or legs from high-speed motorcycle or all-terrain vehicle crash. Despite the higher rate of initial amputation, there was no increase in morbidity, mortality, or length of stay in TQ+ patients.

This study is limited by its observational design and small subset size, which reduces the power of the statistical analysis. Tourniquets were not actively tracked in the registry; thus, identification of cases and assessment of effectiveness had to be extracted from trauma center records. Prehospital and EMS data sets were limited; however, in the local EMS protocol which did not change throughout the study period, tourniquet placement is indicated for any bleeding from an extremity that cannot be controlled with direct pressure. Prehospital personnel carry either the Combat Application or Special Operation Forces Tactical tourniquets. All patients in this cohort had a commercial tourniquet, although two had pre-EMS placement of an improvised tourniquet that was supplemented with a commercial device. There were no documented cases of receiving two commercial tourniquets. The seven cases of tourniquet application after trauma center arrival are potentially missed opportunities for prehospital placement. As this cohort had arterial injuries, all were presumed to have an appropriate indication for use. Fortunately, a majority of these patients had isolated extremity injuries, decreasing the confounding effect of concurrent chest or abdominal trauma. Evaluation through prospective, multicenter studies will allow further characterization of the role of tourniquets in civilian, urban trauma populations.

In conclusion, tourniquet use increased over time in patients with extremity arterial injuries. Patients having prehospital tourniquets required a higher frequency of transfusion and initial amputation, without an increase in complications. Despite the

higher rates of limb loss and transfusion, patients with severe extremity trauma demonstrated a potentially survivable injury that may be related to the use of prehospital tourniquets.

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