the RETURN of TOURNIQUETS

ORIGINAL RESEARCH EVALUATES THE EFFECTIVENESS OF PREHOSPITAL TOURNIQUETS FOR CIVILIAN PENETRATING EXTREMITY INJURIES

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Uncontrolled hemorrhage from isolated penetrating extremity wounds can result in 100% mortality, but significant controversy still surrounds tourniquet use in civilian prehospital care. It's been proposed that 10% of combat deaths in the Vietnam War resulted from uncontrolled hemorrhage from extremity wounds; many of the deaths were due solely to ineffective field hemorrhage control methods.[1] Multiple U.S. and foreign military reports confirm the importance of tourniquets in controlling exsanguination on the battlefield.[2,3] As a result, the use of tourniquets is now actively promoted in the U.S. military, with all service personnel carrying a tourniquet with their gear.[2]

In the civilian trauma setting, the debate continues. In fact, numerous prehospital system medical personnel are specifically discouraged from utilizing tourniquets, and many ambulances don't even carry them. Some of the reasons tourniquets haven't been deployed in the prehospital setting include the notions that: 1) Manual pressure should suffice to control hemorrhage; 2) The proximity of urban trauma centers to the scene of an injury should preclude exsanguination before the patient reaches definitive care; and 3) Tourniquets lead to increased rates of amputation, ischemic complication and neurologic dysfunction.

A 2005 study identified 14 civilian patients who died from isolated penetrating extremity injuries despite reaching the hospital and having injuries that are usually survived into the operating room (OR) for definitive care.[4] None of these patients had a tourniquet applied in the prehospital setting, and the authors report that eight out of the 14 had an injury location amenable to tourniquet use.[4] Further, although an increasing number of reports have recently emerged on the historical use of tourniquets and their theoretical advantages and disadvantages, no studies have attempted to critically examine the role of tourniquets in the civilian trauma setting.[2,5]

In response to fatalities that were considered possibly preventable from isolated extremity vascular injuries, Boston Medical Center (a Level 1 trauma center) and Boston EMS, in the mid-90s, developed unofficial guidelines for the prehospital application of extremity tourniquets. These included penetrating extremity wounds, systolic blood pressure (SBP) < 80 and severe blood loss at the scene—as estimated by the paramedics.

We hypothesized that prehospital tourniquets could safely and effectively control life-threatening extremity vascular injuries, and that highly trained prehospital providers could appropriately apply tourniquets by following the guidelines. We then studied compliance with these guidelines and the outcome of patients who had prehospital tourniquets applied in the field.

This article describes the patients who had the prehospital tourniquets applied, examines the appropriateness of tourniquet application and reports on the effectiveness of prehospital tourniquets on multiple patient outcomes.

BACKGROUND & METHODS

Between January 1999 and April 2006, patients with penetrating extremity wounds who were brought to the BMC Emergency Department (ED) after the application of a prehospital tourniquet were identified from a retrospective review of the trauma database and medical records. Once these patients were identified, their charts were reviewed, including the prehospital patient care report (PCR), the ED trauma record, and all trauma service notes. Collected data for each patient included the following:

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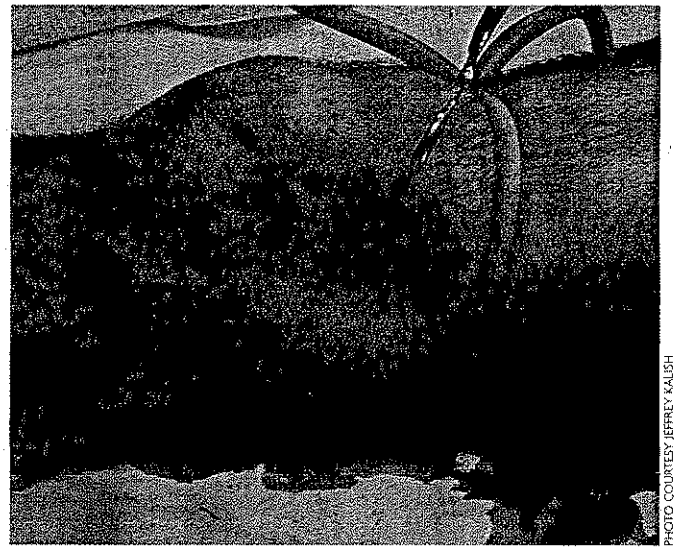
patient demographics, mechanism and location of injury, prehospital vital signs and scene/transport times, ED vital signs and treatment times, tourniquet application times and durations, operative findings, and clinical and extremity outcomes. The BMC Institutional Review Board approved this retrospective study.

RESULTS

Eleven patients were identified as having prehospital tourniquets applied for their penetrating extremity wounds. The mean age of the patients was 27 years, and all were male.



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A distal thigh tourniquet, like the rubber tubing and surgical clamp shown here, is typically required for popliteal and more distal injuries.

Gunshot wounds (GSWs) accounted for six (55%) of the injuries, stab wounds (SWs) for three (27%), and lacerations (LACs) for two (18%). The lower extremity was the site of injury for all GSWs and SWs, and the upper extremity was the site of injury for both LACs.

The mean scene time was 8.5 ± 4.6 minutes (range 3–17 minutes), and the mean transport time was 6.3 ± 1.8 minutes (range 4–10 minutes). The mean tourniquet application time was 75 ± 38 minutes (range 37–167 minutes) (see Table 1).

All patients were taken to the OR for exploration, and the prehospital tourniquets were removed as directed by the operating surgeon. The estimated blood loss (EBL) on scene, as well as the scene blood pressure (BP) and operative findings and functional outcomes for each patient, are shown in Table 2, p. 50.

All six patients with GSW (100%) had an injury to a major artery, and three of those six (50%) had a concomitant injury to a major vein. Only one of the SW patients (33%) had a major arterial injury, and this patient also had a concomitant major venous injury. The other two SW patients (67%) had muscular bleeding only. The two LAC patients (100%) had major arterial injuries in their upper extremities.

Of all the patients, there was one death; this patient was pulseless at the scene and only regained vital signs after CPR. The remainder of the patients survived and were discharged from the hospital.

All patients with injuries to the lower extremities (GSW and SW) retained complete neurologic function post-operatively. All of the vascular repairs were patent in the immediate post-operative period and subsequent early outpatient visits, but long-term follow-up was not possible. Two of the GSW patients (33%) had fasciotomies at the time of operation, and both fasciotomies were closed prior to discharge from the hospital. The two LAC patients had motor and sensory losses, but these deficits resulted directly from primary injuries.

DISCUSSION

Extremity injuries are common on the military battlefield, and tourniquets have been used with increasing frequency and great success in Iraq and Afghanistan to prevent exsanguination and unnecessary mortality. Numerous military reports have confirmed the effectiveness of tourniquets, as well as their safety and low incidence of adverse events.[3,6,7] Nevertheless, controversy persists in civilian settings and within the civilian trauma literature regarding their safety and effectiveness.

As military struggles have re-emerged as a focus in contemporary society, the issues surrounding tourniquet usage have similarly re-emerged for another round of debate. Evidence for this growing interest is the increasing number of historical reports regarding tourniquets that have surfaced in the literature over the past two years.

Two recently published, comprehensive historical reviews delve into the evolution of military tourniquet use and the changing attitudes during different time periods and wars.[2,5] Most recently, the 2004 revision of *Emergency War Surgery* issued by the U.S. government again urged the early application of tourniquets to arrest blood loss.[8]

Further, the U.S. military has kept the pendulum swinging in favor of tourniquet use because of its recent mandate to issue a Combat Application Tourniquet (C.A.T.) to all field troops in Afghanistan and Iraq. Although no data has been published, anecdotal reports indicate these self-applied tourniquets are beneficial for extremity injuries.[2]

A retrospective review of tourniquet use by the Israeli Defense Force (IDF) found that application of an elastic/silicone band was effective in arresting hemorrhage in 71% of

Table 1: Prehospital & Tourniquet Times in Patients with Penetrating Extremity Injuries

Patient	Mechanism	Extremity	Scene Time (min)	Transport Time (min)	Tourniquet (min)
1	GSW	Lt thigh	10	10	167
2	GSW	Rt thigh	5	5	47
3	GSW	Lt thigh	12	7	70
4	GSW	Rt knee	3	5	81
5	GSW	Lt knee	11	5	53
6	GSW	Rt thigh	8	7	77
7	Stab	Rt thigh	10	10	43
8	Stab	Rt thigh	7	7	37
9	Stabs	B/L thighs	17	4	72
10	Laceration	Rt forearm	5	10	57
11	Laceration	Rt forearm	10	7	120
	Mean ± Standard Deviation		8.5 ± 4.6 min	6.3 ± 1.8 min	75 ± 38 min

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lower extremity wounds and 94% of upper extremity wounds.[3] Only 53% of the tourniquet applications were indicated based on guidelines created by the IDF. Those authors conceded that inappropriate use was attributable to stressful situations coupled with the insufficient experience of most of the medical care providers.

Despite the overuse of tourniquets in this study, neurologic complications occurred in only 5.5% of the patients.[3] This low complication rate was a direct result of rapid evacuation and early in-hospital definitive surgical care, resulting in short ischemic times of two to three hours.

CIVILIAN USE

Although tourniquet use receives tremendous attention in military arenas, to date no other attempts have been made to examine tourniquet use in the civilian setting. The most applicable study in the civilian trauma literature was a retrospective study of 14 patients who died from isolated penetrating extremity injuries despite reaching the hospital.[4]

Twelve of the 14 patients (86%) showed signs of life in the field and underwent CPR en route to the hospital. Nine patients (63%) underwent immediate ED thoracotomy (ECT) and one patient (7%) had CPR only, while four patients (28%) were declared dead on arrival.

Nine patients (63%) were resuscitated and taken to the OR. Unfortunately, all of the patients died, with 93% succumbing to their isolated injury within 12 hours. Prehospital hemorrhage control was primarily performed by gauze dressings, and the authors report that eight out of the 14 patients had an injury location amenable to a tourniquet.[4]

As a result of the shortage of information on civilian tourniquet use, the small retrospective analysis by BMC/BEMS represents the first attempt to examine the role of prehospital tourniquets in a critical fashion.

TOURNIQUET TIPS

For many years BMC trauma surgeons have employed tourniquets under certain circumstances and developed specific criteria for their use. Like many of the tourniquets employed in World War II and the Vietnam War, this tourniquet consists simply of 1/2" circular rubber tubing and a surgical clamp (preferably a Kelly clamp). The tubing is stretched and wrapped once around the most distal part of the extremity to control the hemorrhage, and the tubing is then secured with the clamp. In the proximal thigh, a double wrap of the tubing is usually necessary.

In a recent study from the Canadian military, this same rubber-tubing tourniquet was praised for its effectiveness, ease of use, low cost and lightweight/durable nature.[7]

FAST FACTS

- Mean age of the patients was 27 years. All were male.
- Gunshot wounds (GSWs) accounted for six (55%) of the injuries, stab wounds (SWs) for three (27%), and lacerations (LACs) for two (18%).
- The lower extremity was the site of injury for all GSWs and SWs, and the upper extremity was site of injury for both LACs.
- Mean EMS scene time was 8.5 ± 4.6 minutes (range 3–17 minutes).

Other tourniquets, such as the C.A.T., offer a wide band that can be applied and secured with one hand, and a large, pre-attached windlass that's rotated three times for hemorrhage control, secured in a "U"-shaped holder and locked safely in place by a Velcro® tab.

The most critical point in the application of any tourniquet is that it be tightened with enough pressure to impede both arterial inflow and venous outflow. The lower leg usually doesn't provide a good location for tourniquet application because the tibia and fibula preclude adequate arterial compression; therefore, a distal thigh tourniquet is typically required for popliteal and more distal injuries.

The 11 patients identified in this study had tourniquets applied in the prehospital setting by BEMS EMTs and paramedics. Although no official tourniquet guidelines had been sanctioned for EMTs or paramedics in Boston or anywhere else in the country, BMC trauma surgeons and BEMS cooperated in developing proposed guidelines for tourniquet use.

Each application of a tourniquet was subjected to a case-specific follow-up

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discussion regarding the indications for and technique of tourniquet application. Based on the arterial injuries encountered in nine of the 11 patients, our study confirmed the appropriateness of these inclusion criteria for determining the need for a prehospital tourniquet and for limiting the number of false positive applications.

More specifically, all six GSW patients (100%) met the inclusion criteria and also had an injury to a major artery requiring repair. There was only one death. This patient was similar to the patients described in Dorlac's series, in which all died even if they survived through the operative period.[4]

One of the Boston SW patients (33%) met inclusion criteria and had a major arterial injury requiring repair. One SW patient (33%) had a blood pressure of 126 (thus not meeting criteria), and didn't have a major arterial injury. (Note: This patient was flagged as a violation of the tourniquet protocol having not warranted a tourniquet.)

The third SW patient was a paraplegic with multiple concomitant stab wounds who was discovered in a chaotic scene involving a suicide attempt, thus precluding a reliable assessment of the need for a tourniquet by the paramedics.

One of the two LAC patients (50%) met the tourniquet criteria, and both had major upper extremity arterial injuries. However, it's possible that these patients could've had their hemorrhages controlled with other methods, such as direct pressure.

As tourniquet opponents have argued for many decades, ischemic and neurological complications can occur if a tourniquet is used improperly.[9] However, in this study, no injuries resulted in any neurologic compromise caused specifically by tourniquet use, with mean tourniquet application times as short as 75 ± 38 minutes (range 37–167 minutes). The two patients with upper extremity injuries did suffer motor and sensory loss, but these deficits were the result of the penetrating injuries themselves, not the tourniquet application. Even patients who required fasciotomies had those wounds closed prior to discharge, with no long-term sequelae from any ischemia due to the tourniquet.

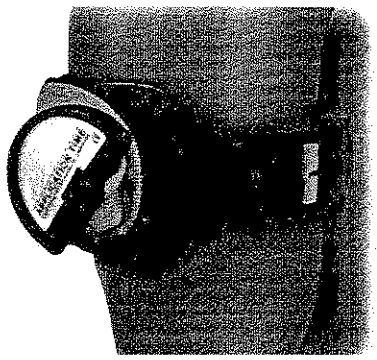

PHOTO COURTESY PYNG MEDICAL CORP.

The MAT (Mechanical Advantage Tourniquet) is easy to apply and tighten with one hand.

Given short transit times and rapid movement of patients into an OR for definitive vascular control, tourniquet times can easily be limited to fewer than three hours. In such short periods of time, the ischemia and reperfusion that occur shouldn't lead to irreversible muscle cell damage or prolonged systemic inflammatory responses.[10] Further, trauma surgeons can heed the lessons from successful tourniquet use in ORs across the country for various orthopedic and vascular procedures.[11-13]

Before removing an appropriately placed and functioning tourniquet, it's critical that the patient is in the proper arena with definitive surgical control achieved (i.e., the OR with proximal arterial control). With a policy in place for prehospital tourniquet application and strict criteria established for tourniquet use, surgeons should rely on the prehospital system to determine which patients need definitive care in an OR.

The importance of case-by-case evaluation and appropriate feedback can't be underestimated, because an effective prehospital tourniquet policy can be successful only when there's continued post-operative communication between the trauma surgeons caring for the patients and the prehospital crews making the initial decisions in the field.

This study has numerous limitations given the small sample size and lack of a true control group. Additional concerns include selection bias and the difficulties inherent to chart review. Last, the findings may not be applicable to EMS providers outside of the urban trauma environment or within systems that lack coordination

With proper education and training, tourniquets can be adopted into the prehospital system without adverse effects on limb salvage or functional outcome.

Table 2: Demographics, Injuries & Outcomes in Patients with Penetrating Extremity Injuries

Patient	Age/Sex	Mechanism	Extremity	EBL (field)	SBP (field) (mmHg)	Injury (Artery/Vein)	Outcome
1	44/M	GSW	Lt thigh	Unknown	<80	AK pop/SFV	Fasciotomy closed
2	16/M	GSW	Rt thigh	Heavy	62	SFA/SFV	Normal
3	29/M	GSW	Lt thigh	Heavy	0 (80 after CPR)	SFA	"Expired (PE, brain death)"
4	22/M	GSW	Rt knee	2 Liters	60	Pop	Normal
5	30/M	GSW	Lt knee	Heavy	Not palp	Pop/pop	Fasciotomy closed
6	32/M	GSW	Rt thigh	Heavy	80	Profunda	I+D's Rt hip
7	24/M	Stab	Rt thigh	Heavy	80	Pop/pop	Normal
8	16/M	Stab	Rt thigh	Heavy	126	Muscle	Normal
9	27/M	Stabs	B/l Thighs	Bloody tub	78	None	Already T4 paraplegic
10	30/M	Laceration	Rt forearm	Heavy	98	Brachial/brachial	"Fasciotomy, preop motor+sensory loss"
11	28/M	Laceration	Rt forearm	Heavy	Not palp	Radial+ulnar	Preop motor+sensory loss

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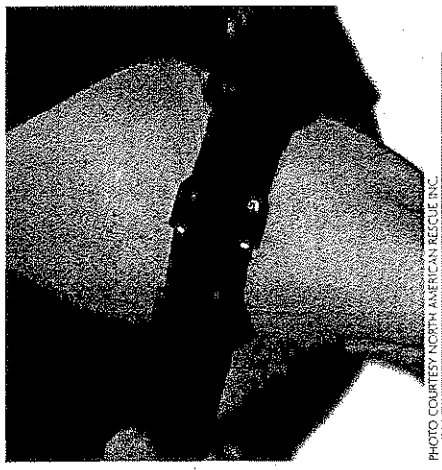
between prehospital providers and the hospital trauma services.

CONCLUSION

Tourniquets have been incorporated into trauma care for many centuries, and the debate regarding their utility has continued for the same amount of time. Prospective studies are nonexistent; retrospective studies are sparse. This is especially evident in civilian trauma literature. Unfortunately, anecdotal reports thus comprise the foundation for physicians' and paramedics' opinions of this uncomplicated medical procedure.

The BMC/BEMS cohort study indicates that prehospital tourniquets can be appropriately applied to control life-threatening hemorrhage from an extremity injury, and that their use isn't associated with neurovascular complications. In similar case series, some of the patients we've described appear to have died because of inadequate hemorrhage control. It's thus quite unlikely that a well-controlled clinical trial could be conducted to truly determine the safety and efficacy of this intervention. Nevertheless, our findings emphasize the need to re-evaluate the standard teaching that tourniquets are to be used only as a last resort because of safety concerns.



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The C.A.T. (Combat Application Tourniquet) is a one-hand tourniquet that features a pre-attached windlass and "U"-shaped holder and Velcro® strip, which locks it securely in place.

We believe properly applied tourniquets can safely, rapidly and effectively control life-threatening bleeding from a penetrating extremity injury. Further, we believe this intervention should be more routinely considered, especially in prehospital systems that have appropriate quality control procedures. JEMS

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Erwin Hirsch, MD, (1936–2008) was chief of trauma surgery at Boston Medical Center for more than 25 years. He taught surgery and directed the Medical Education and Inter-regional Harmonization Program for Nuclear Accident Preparedness at the Boston University School of Medicine. He created Boston MedFlight, a non-profit that uses air and ground vehicles to transport patients, and served on its board of directors.

This article is dedicated to the memory of Erwin Hirsch, MD. Dr. Hirsch died unexpectedly in May. He was an icon who saved thousands of lives, modernized EMS by redefining the way trauma is treated and was among the first to welcome female surgeons in the operating room. He helped make Boston Medical Center one of the nation's premiere trauma centers and was instrumental in securing its Level 1 Trauma Center designation.

REFERENCES

1. Bellamy RF: "The causes of death in conventional land warfare: Implications for combat casualty care research." *Military Medicine.* 149(2):55–62, 1984.
2. Welling DR, Burris DG, Hutton JE, et al: "A balanced approach to tourniquet use: Lessons learned and relearned." *Journal of the American College of Surgeons.* 203(1):106–115, 2006.
3. Lakstein D, Blumenfeld A, Sokolov T, et al: "Tourniquets for hemorrhage control on the battlefield: A 4-year accumulated experience." *Journal of Trauma.* 54(5 Suppl):S221–S225, 2003.
4. Dorlac WC, DeBakey ME, Holcomb JB, et al: "Mortality from isolated civilian penetrating extremity injury." *Journal of Trauma.* 59(1):217–222, 2005.
5. Mabry RL: "Tourniquet use on the battlefield." *Military Medicine.* 171(5):352–356, 2006.
6. Calkins D, Snow C, Costello M, et al: "Evaluation of possible battlefield tourniquet systems for the far-forward setting." *Military Medicine.* 165(5):379–384, 2000.
7. King RB, Filips D, Blitz S, et al: "Evaluation of possible tourniquet systems for use in the Canadian forces." *Journal of Trauma.* 60(5):1061–1071, 2006.
8. Burris DG, FitzHarris JB, Holcomb JB, et al (eds): *Emergency war surgery.* Third U.S. revision. United States Department of Defense. Washington, D.C., 2004.
9. Navein J, Coupland R, Dunn R: "The tourniquet controversy." *Journal of Trauma.* 54(5 Suppl):S219–S220, 2003.
10. Blaisdell FW: "The pathophysiology of skeletal muscle ischemia and the reperfusion syndrome: A review." *Cardiovascular Surgery.* 10(6):620–630, 2002.
11. Kam PC, Kavanagh R, Yoong FF: "The arterial tourniquet: Pathophysiological consequences and anaesthetic implications." *Anaesthesia.* 56(6):534–545, 2001.
12. Wakai A, Winter DC, Street JT, et al: "Pneumatic tourniquets in extremity surgery." *Journal of the American Academy of Orthopaedic Surgeons.* 9(5):345–351, 2001.
13. Choksy SA, Chong PL, Smith C, et al: "A randomized controlled trial of the use of a tourniquet to reduce blood loss during transtibial amputation for peripheral arterial disease." *European Journal of Vascular and Endovascular Surgery.* 31(6):646–650, 2006.