The Journal of Emergency Medicine, Vol. xx, No. x, pp. xxx, 2009
Published by Elsevier Inc.
Printed in the USA
0736-4679/09 $–see front matter

ELSEVIER

doi:10.1016/j.jemermed.2009.07.022

# Original Contributions

## BATTLE CASUALTY SURVIVAL WITH EMERGENCY TOURNIQUET USE TO STOP LIMB BLEEDING

John F. Kragh, Jr, COL, MC, USA,* Michelle L. Littrel, CPT, AN, USA,† John A. Jones,* Thomas J. Walters, PHD,* David G. Baer, PHD,* Charles E. Wade, PHD,* and John B. Holcomb, MD*†

*US Army Institute of Surgical Research (USAISR), Fort Sam Houston, Texas and †Department of Nursing, Brooke Army Medical Center, Fort Sam Houston, Texas

*Reprint Address*: John F. Kragh, Jr, COL, MC, USA, Bone and Soft Tissue Trauma Research Program, US Army Institute of Surgical Research, 3400 Rawley E. Chambers Ave., Bldg. 3611, Room L82-16, Fort Sam Houston, TX 78234-6315

□ **Abstract—Background: In a previous study conducted at a combat support hospital in Iraq, we reported the major lifesaving benefits of emergency tourniquets to stop bleeding in major limb trauma. Morbidity associated with tourniquet use was minor. Study Objectives: The objective of this study is to further analyze emergency tourniquet use in combat casualty care. Design and Setting: This report is a continuation of our previous study of tourniquet use in casualties admitted to a combat support hospital (NCT00517166 at www.ClinicalTrials.gov). Methods: After verifying comparable methodologies for the first study and the current study, we compared patient results for these two time periods and then pooled data to analyze outcomes with a larger sample size. Results: The total study population was 499 (232 in the previous study and 267 in the current study). In all, 862 tourniquets were applied on 651 limbs. Survival was 87% for both study periods. Morbidity rates for palsies at the level of the tourniquet were 1.7% for study 1 and 1.5% for study 2; major limb shortening was 0.4% for both. Survival was associated with prehospital application (89% vs. 78% hospital, $p < 0.01$) and application before the onset of shock (96% vs. 4% after). Conclusions: This study shows consistent lifesaving benefits and low risk of emergency tourniquets to stop bleeding in major limb trauma. Published by Elsevier Inc.**

□ **Keywords—tourniquet; trauma; major; military; limb injury; hemorrhage control**

## INTRODUCTION

Despite recent positive reports of the use of emergency tourniquets from studies conducted at United States (US) combat support hospitals in Iraq, these devices are still considered controversial by some providers (1,2). We recently reported major lifesaving benefits and minor morbidity risks with emergency tourniquet use to stop bleeding in major limb trauma (3,4). Our goal was to see if our preliminary findings would hold true as the war progressed and tourniquets continued to be used. The fielding of tourniquets during the current war and the number of casualties permitted us to study and continue to evaluate performance (5,6). Improving prehospital hemorrhage control is vital to military and civilian trauma care, and we continue our efforts to fill knowl-

This study was performed at the 10th & 28th Combat Support Hospitals, US Army, (Ibn Sina Hospital, International Zone, Baghdad, Iraq). The trial number is NCT00517166 at www.ClinicalTrials.gov.

The opinions or assertions contained herein are the private views of the authors and are not to be construed as official or reflecting the views of the Department of Defense or United States Government. The authors are employees of the US government. This work was prepared as part of their official duties and, as such, there is no copyright to be transferred.

RECEIVED: 28 October 2008; FINAL SUBMISSION RECEIVED: 11 May 2009;
ACCEPTED: 10 July 2009

edge gaps regarding first aid of limb-injured patients (7–13). There is no consensus on tourniquet use in civilian trauma, but an adequate collection of military data may help to change this. In our continued study of patients who had tourniquets applied in the field or in the emergency department (ED), our objective was to analyze use and possibly refine our understanding of when and if tourniquets should be used as first aid, to refine doctrine and training if indicated. Specifically, our objective was to assess morbidity and mortality associated with tourniquet use.

## MATERIALS AND METHODS

### *Study Design, Setting, and Participant Selection*

The current report was designed to test the consistency of the findings of our previous reports on emergency tourniquet use (3,4). The design was an observational study of patient care; there was no experiment or intervention. Before the study began we predetermined the data of interest, that is, possible morbidity as well as the mortality rates with the use of tourniquets. The study was approved by our institutional review board as part of an ongoing prospective performance improvement project on tourniquet use (NCT00517166 at www.ClinicalTrials.gov). The informed consent waiver was approved. Procedures followed were in accord with the Helsinki Declaration of 1975.

The setting was a military hospital in support of combat and related security work in Iraq, where casualties, including civilians, were admitted directly or transferred from forward surgical teams. Prehospital tourniquets were applied by people with a wide range of medical skills and included casualties themselves, lay bystanders, soldiers, medics, nurses, and doctors. Tourniquets are part of standard prehospital care to stop bleeding in combat and are often used before pressure dressings during care under fire. All deployed US servicepersons get tourniquet training with instructions to apply them as soon as possible to stop potentially lethal external limb bleeding; the soldiers were taught how to use the tourniquets using a simplified form of Tactical Combat Casualty Care in Prehospital Trauma Life Support (14). The aim of tourniquet use is to prevent hemorrhagic shock and save lives while minimizing morbidity. Casualties were eventually transferred to other hospitals for definitive care.

All patients at the combat support hospital who had a tourniquet of any type used in their emergent health care were included in the study. Patients with tourniquets ready at the bedside, purposefully left loose, or whose first applied tourniquet was in the hospital operating room, were excluded. Detainees and prisoners of war are restricted from research by military policies and were also excluded.

The study period was 1 year, divided into two consecutive 6-month time periods. The primary investigator (first author), an orthopedic surgeon with extensive experience with emergency tourniquet use, was the site investigator for the first time period; the second author, a registered nurse new to tourniquets, was the site investigator for the second time period. The nurse was a founding member of a deployed research team. Hospital providers were replaced at the same time as the investigators.

### *Methods of Measurement*

We evaluated tourniquet use in two ways. We categorized patients by whether their tourniquets were applied prehospital or in the ED, and also when they were placed physiologically in relation to shock. ED tourniquet patients were those patients who had a tourniquet first placed on a limb in the ED; the other patients had a tourniquet placed on a limb in the prehospital setting.

Shock was defined by medics or hospital providers as a weak or absent radial pulse in an uninjured limb without a tourniquet. Patients with tourniquets first placed after the onset of shock were analyzed as “shock present,” and all other patients were “shock absent” before application of first tourniquet. This validated approach is consistent with the clinical definitions used by the Tactical Combat Casualty Care course, taught to all military medics, and correlated with systolic blood pressures as described by McManus et al. (14,15).

Survival rate was the primary outcome and morbidity rate was the secondary outcome. We defined indicated and appropriate use by the following criteria: indicated use was medical (vessel lesion hemorrhage unresponsive to a pressure dressing) or tactical for care under fire; appropriate use entailed no misplacement (e.g., wrong limb or distal to a wound), purposeful venous tourniquet, or misuse (e.g., upside down).

Data were collected prospectively by the two on-site investigators. Data were collected from the patients, their providers or attendants, records, or medical reports such as the morbidity and mortality reports. We had access to electronic records of casualties. Data collected included patient age, gender, application time (time between injury and use) in minutes, setting of tourniquet application (prehospital or ED), mechanism of injury, treatment (including operative procedures, number of transfused units [all blood products were summed]), injury severity scores, abbreviated injury score (AIS), base deficit, systolic blood pressure, international normalized ratio, initial heart rate, injury description (e.g., traumatic ampu-

**Table 1. Comparison of Key Variables of the Two Time Periods**

| Study Population Variable | Unit % n = 499 | Study | | *p* Value |
|---|---|---|---|---|
| | | Previous n = 232 | Current n = 267 | |
| Mechanism of injury: explosion | % of Mechanisms | 69 | 75 | 0.14 |
| Use site | | | | |
| Prehospital | % of Patients | 84 | 86 | 0.51 |
| Emergency department | % of Patients | 16 | 14 | 0.51 |
| Survival rate | % of Patients | 87 | 87 | 0.95 |
| Morbidity rate | | | | |
| Palsy | % of Patients | 1.7 | 1.5 | 0.84 |
| Major limb shortening | % of Patients | 0.4 | 0.4 | 0.92 |

tation, open fracture, artery lesion), outcome (e.g., limb salvage, death), complications (e.g., necrotic muscle, compartment syndrome, nerve palsy), and duration of follow-up.

### *Statistical Analysis*

For comparison of time periods 1 and 2, we compared proportions of key variables such as survival rates. We used descriptive statistics and Fisher's exact test for contingency testing. Software included Excel (version 97, Microsoft Corporation, Redmond, WA), and SAS/STAT (version 9.1, SAS Institute, Cary, NC).

## RESULTS

The two study periods were similar for the number of patients, deaths, palsies at the level of the tourniquet, and limbs with major shortening, so these data were consistent (Table 1), and therefore we pooled data for further analysis.

### *Study Group Demographics*

The study group consisted of 499 patients from 13 nations, and included 257 Iraqis and 226 Americans. There were 479 males and 20 females, 16 children and 5 elderly patients. The average age was 29 years. Follow-up averaged 36 days.

There were 862 tourniquets applied to 651 limbs (328 left and 323 right; 176 upper limbs and 475 lower limbs). For the 862 tourniquets with known number per limb, one tourniquet was used in 445 limbs, two tourniquets were used in 166 limbs, three tourniquets were used in 24 limbs, four tourniquets were used in two limbs, and five tourniquets were used in one limb. For 875 tourniquets, the study averaged 1.4 patients and 2.4 tourniquets per day, with 1.3 tourniquets per limb. The body regions (forearm, arm, leg, and thigh) where the tourniquets were applied included 13 forearms, 162 arms, 46 legs, and 436 thighs. Eight limbs had tourniquets applied above and below the major joints (knee or elbow). For two limbs, data on which body region had the tourniquet were missing.

The patients showed pathophysiology associated with hemorrhage and coagulopathy (Table 2).

### *Indicated and Unindicated Emergency Tourniquet Use*

Of all 651 limbs (499 patients), 635 (483 patients) had indicated tourniquet use. There were 16 limbs (15 patients) that had tourniquets applied but did not have a medical or tactical indication. Of the 15 patients, one Iraqi had a right biceps brachii soft tissue injury, but had a tourniquet applied prehospital to the left upper extremity. The tourniquet was removed in the ED; it had been

**Table 2. Pathophysiologic Data Summary of the Study Group**

| | n | Average ± SD | Median | Minimum | Maximum |
|---|---|---|---|---|---|
| Initial base deficit | 424 | −6 ± 6.5 | −4 | −27 | 3 |
| Initial heart rate | 464 | 105 ± 32.5 | 107 | 0 | 208 |
| INR (international normalized ratio) | 414 | 1.6 ± 3.8 | 1.2 | 0.6 | 74 |
| Transfusion units | 472 | 16 ± 25.6 | 6 | 0 | 194 |

SD = standard deviation; n = number of patients with data.

used for 25 min. The patient had no morbidity from the tourniquet, and this use was unindicated medically (a pressure dressing sufficed) and misplaced (wrong limb). For this one patient, the tourniquet was indicated for care under fire. Fourteen patients had 15 tourniquets for 15 soft tissue injuries that were converted to pressure dressings in the ED, and no tactical indication was present prehospital for these 14 patients. A prehospital pressure dressing would have sufficed for the 15 wounds. Of the 16 unindicated tourniquets, the maximum tourniquet duration was 2 h, and none of the 16 limbs had morbidity.

### *Appropriateness, Inappropriateness, and Misuse of Emergency Tourniquet Use*

All patients except one had emergency tourniquet use that was appropriate. All were aimed at being an arterial tourniquet except for one patient who had a purposeful venous tourniquet. This one patient, with open type 3B tibia and fibula shaft fractures, had a medically indicated tourniquet used inappropriately as a venous tourniquet in the ED. The patient also had 40% body surface area burns. No complications other than blood loss were attributable to inappropriate tourniquet use, and tourniquet replacements or corrections were made on the spot (3).

Misuse occurred in 13 cases, including the patient described above who had a tourniquet placed on the wrong limb (Table 3). These problems were addressed with improved training, device design refinements, and more device testing and maintenance procedures.

### *Survival Rate was Higher in Patients with Tourniquets Used vs. Not Used*

Ten patients who came to our hospital during the study period had isolated limb exsanguination amenable to tourniquet application, but tourniquets were either unavailable (none at scene), inaccessible (packed away and found after the patient died), or not placed in time after extrication from vehicles or after transport before the patient died. Cause of death in all 10 patients was exsanguination from limb injuries. In contrast to the 10 casualties without tourniquets, in the 499 casualties with tourniquets, 16 of the 65 deaths were from isolated limb exsanguination, often with tourniquets placed after shock onset (19 had severe [AIS 3 to 6] head wounds, 15 had severe abdominal wounds, 7 had severe chest wounds, 4 had severe burns, and 2 had two or more equally severe body regions injured). From the 10 patients without tourniquets (0% survival) and the 499 with tourniquets (87% survival), we measured the mortality rate of patients who exsanguinated from isolated limb injuries at 2% (10/519).

**Table 3. Misuse Occurrences**

| |
|---|
| One patient had a tourniquet on a wrong limb |
| One patient had upside-down use of a pneumatic tourniquet |
| Users twisted the air release cap off and thus broke two pneumatic tourniquets |
| One bar broke on a windlass tourniquet |
| One clamp jammed on a pneumatic device |
| One pneumatic bladder folded over and jammed in the clamp |
| One pneumatic bulb popped off |
| One tourniquet bar with a smooth texture was too bloody and slippery to secure |
| Four pneumatic bladders leaked (scalpel or needle dropped on it during catheterization) |

**Table 4. Results Comparing Survival of Patients with Tourniquets Used vs. Not Used**

| Time Period | Patients with Tourniquet Use with Shock Absent (n Survivors/n Total, %) | Patients with Tourniquet Use with Shock Present (n Survivors/n Total, %) |
|---|---|---|
| 1 | 222/232, 96% | 10/232, 4% |
| 2 | 255/267, 96% | 12/267, 4% |
| Pooled | 477/499, 96% | 22/499, 4% |

### *Survival Rate was Higher When Shock was Not Present before Tourniquet Use Compared to When Shock was Present*

The results of tourniquet use with shock present vs. absent were consistent in the two time periods, so we pooled the data (Tables 4, 5). Overall, patients had a 90% (429/476) survival when tourniquets were applied before shock, compared to an 18% (4/22) survival when placed after the onset of shock (Table 5). Tourniquet use in the absence of shock was associated with survival ($p < 0.001$), and prehospital use was associated with survival ($p = 0.015$; Table 6).

Prehospital use was associated with shock absence and ED use was associated with shock presence ($p <$

**Table 5. Survival Rates by Prehospital vs. ED Tourniquet Use and Shock Present vs. Absent at the Time of Application**

| | Shock Absent | Shock Present |
|---|---|---|
| Hospital | | |
| Prehospital | 90% | 20% |
| Emergency department | 93% | 23% |

ED = emergency department.

**Table 6. Shock, Survival, and Setting Results from 2-by-2 Contingency Testing**

| | |
|---|---|
| Given shock presence, prehospital vs. ED use was not associated with survival | $p = 1.0$ |
| Given shock absence, prehospital vs. ED use was not associated with survival | $p = 0.5$ |
| Given survivors, prehospital vs. ED use was associated with shock (absent vs. present) | $p < 0.001$ |
| Given non-survivors, prehospital vs. ED use was associated with shock (absent vs. present) | $p < 0.001$ |
| Given prehospital use, shock (absent vs. present) was associated with survival | $p < 0.001$ |
| Given ED use, shock (absent vs. present) was associated with survival | $p < 0.001$ |
| Prehospital vs. ED use was associated with survival without considering shock | $p = 0.015$ |
| Shock (absent vs. present) was associated with prehospital vs. ED use without considering survival | $p < 0.001$ |
| Shock (absent vs. present) was associated with survival without considering prehospital vs. ED use | $p < 0.001$ |

ED = emergency department.

0.001; Table 6). Survival was associated with use both before shock onset (96% before vs. 4% after, 477/499 vs. 22/499, respectively) and prehospital (89% prehospital vs. 78% hospital, 374/422 vs. 59/76, respectively, $p = 0.015$; Table 5).

## DISCUSSION

The main finding of the present report is that the major lifesaving benefits of emergency tourniquet use were observed again, and the consistent finding reinforces the recommendation to consider tourniquets in similar care settings. Additionally, the minor morbidity risks were also consistent with the prior reports (3,4). Despite different providers, patients, and site investigators, albeit at the same site using the same methods, the consistent findings increase the generalizability of the previous reports. Rarely is evidence available to show that first aid is lifesaving for limb-injured patients. The only analogous device to the tourniquet is the Thomas splint, which also controls hemorrhage in battlefield open femur fractures (16,17). Most first aid devices are similar to pelvic binders, that is, they have no survival benefit evidenced, and military anti-shock trousers are associated with *increased* mortality for patients with some diagnoses (18).

A minor finding of the present report was that prehospital death rates from isolated limb exsanguination have dropped to 2%, compared to 9% in the Vietnam War. Tourniquets can control limb hemorrhage, a leading cause of death on the battlefield, with more frequent tourniquet use attributed to fewer deaths from this cause (3,5,6,19–24). In the Vietnam War, when tourniquet use was uneven, about 9% of casualties died from isolated limb exsanguination (7,25). In Somalia, tourniquet use was more common than in Vietnam, and 7% of battlefield casualties died of limb exsanguination (26). Early in the current war, 2% of casualties died from isolated limb exsanguination, and isolated limb exsanguination is no longer considered the leading cause of preventable death on the battlefield in US casualties (27,28). Among Israeli soldiers, the most avid users of tourniquets, investigators found that 0% patients died from isolated limb exsanguination (29).

After studying 499 casualties, it is clear that patients were eligible for tourniquet use in emergency settings if they had a compressible limb area proximal to a wound that risks lethal exsanguination. The tourniquet was not designed to save patients with associated catastrophic head, chest, and abdominal injuries. One patient beyond saving had a traumatic hemipelvectomy; no compression was effective about the hemipelvectomy wound. Very proximal wounds in the groin and axilla have poor results if lesions are non-compressible, lesions of intermediate compressibility have intermediate results, and fully compressible lesions have good results (4). The present findings help define which patients are the best candidates for emergency tourniquet use.

The data of the present study indicate that the ideal time to use a tourniquet is before the onset of shock. Shock prevention seems to be a determinant of survival, and prehospital tourniquet use simply treats more patients before shock onset. The main lifesaving opportunity on the battlefield is prehospital hemorrhage control for limb-injured patients (7,25,30,31). The evidence indicates that tourniquets prevent but do not reverse shock. Use may prevent shock from worsening, and may lessen the risk of additional resuscitation and its sequelae.

The wrong time is late, after shock onset, meaning that, by then, much of the lifesaving benefit has been lost. Casualties with tourniquets applied after extrication from vehicles or when casualties exsanguinated before care was given have a high mortality. Hemorrhage can be incremental during transportation, arrival at hospital, during resuscitation, and before, during, and after operation, thus, continuous monitoring for hemorrhage control is recommended (4,22,24,32,33). Even though providers such as ambulance and flight medics provide prehospital care, tourniquet use at such time proved to be too late after shock onset, and earlier use would prevent shock. Battle casualties may exsanguinate rapidly from limb injury, perhaps lethally, in just a minute or 2 (19,26,30,34–37). Casualties sometimes died quickly from hemorrhage without tourniquets, whereas others with tourniquets survived more often and for a longer time, and longer survival permitted more effective resus-

citation (4). We were able to save several patients who had lost vital signs, and tourniquets were also an adjunct to other damage control resuscitation measures (38).

Tourniquet issue to individual soldiers is justified in war, as early use was associated strongly with more lives saved. Tourniquets should be available (with the individual soldiers), accessible (easily found in first aid kits), and used before shock onset for lifesaving benefit. Searching through a series of other persons' packs to find enough tourniquets to treat casualties loses precious time. The accessibility of the individual first aid kit, a standard issue item, applied on the front side of the torso body armor, was common and ideal; burying tourniquets in the bottom of a rucksack or a vehicle bin was lethal.

Misuse of tourniquets increases morbidity and mortality, whereas using them in the right way improves survival with minor morbidity (3,4,32). Snug tourniquets stay in place and reliably occlude the arteries (assuming the tourniquet is wide enough for the limb). Loose tourniquets slide around and may not occlude the arteries or veins. Looseness was associated with clothing, equipment, or pocket cargo under the tourniquet, and movement of the patient or limb in evacuation or transfer. Looseness was associated with rebleeding and death. Looseness is an example of why monitoring and rechecking patients is vital. Awareness and vigilance of the myriad ways that hemorrhage can occur, continue, or recur in casualties, especially in the first 2 days after injury, are vital lessons relearned (24,33). Clothing was associated with missed wounds proximal to the location of the tourniquet, and such clothing and resultant distal tourniquet use was associated with death (3). In these 499 patients, we noted occasional problems with tourniquets that broke, bladders that were cut by dropped needles and knives, and a tourniquet used upside down.

Population risk assessment for major limb injury and lethal exsanguination seems prudent when determining if tourniquets are right for the population. Awareness of how much limb casualties bleed is limited, even on the battlefield (20,21,23,24,39,40). The data indicate that emergency tourniquets are tools which, if used correctly, are helpful and carry only minor risk. If misused, there is an increased risk of mortality and morbidity. More studies are needed to determine when tourniquets should be applied.

The risk of morbidity associated with tourniquets, such as temporary nerve palsy and limb shortening, was consistent and low for both study periods (1.7%, 1.5%, and 0.4%, 0.4%, respectively). Thus, in light of the major lifesaving benefit, the minor morbidity risk justifies the policy of encouraging tourniquet use in the current war.

*Limitations*

Limitations of the present report are that it does not detail morbidity and that it is a wartime study. Wartime constrained us to a practical, prehospital definition of shock with manual vital signs, for example, loss of radial pulse in an uninjured limb, which generally concords with class 3 and 4 hemorrhagic shock. Such prehospital definitions of shock are practical and valid but have limitations, including limited study in the civilian community. The scientific merit of a randomized prospective trial would be great by limiting confounding variables, but it would be unethical. Dead casualties might have had undetected lesions. Persons with limited training most frequently made the decision to use tourniquets; there were no controls for injury severity or other confounding variables like head or torso injuries. The costs of fielding tourniquets (the standard Combat Application Tourniquet costs about $28) and training soldiers were not studied.

Further research should include detailed morbidity analyses, cohort studies comparing use vs. non-use from databases like the military trauma registry, studies comparing medical (anatomic lesions) vs. tactical indications, and study at sites other than Baghdad to assess generalizability further. In real-world shock studies, confounding exists because individual casualties have different propensities to develop shock, perhaps based on their initial blood volume or genetic make-up.

## CONCLUSIONS

Battle casualty survival rates are consistently high with emergency tourniquet use to stop bleeding, and morbidity rates remain low. Evidence indicates that when used at the right time in the right way, emergency tourniquets are lifesaving.

## REFERENCES

1. Husum H, Gilbert M, Wisborg T, Pillgram-Larsen J. Prehospital tourniquets: there should be no controversy. J Trauma 2004;56: 214–5.
2. Husum H, Ang SC, Fosse E. War surgery field manual. Penang, Malaysia: Third World Network; 1995.
3. Kragh JF Jr, Walters TJ, Baer DG, et al. Practical use of emergency tourniquets to stop bleeding in major limb trauma. J Trauma 2008;64:S38–50.
4. Kragh JF, Walters TJ, Baer DG, et al. Survival with emergency tourniquet use to stop bleeding in major limb trauma. Ann Surg 2009;249:1–7.
5. Mabry RL. Tourniquet use on the battlefield. Mil Med 2006;171: 352–6.
6. Beekley AC, Sebesta JA, Blackbourne LH, et al. Prehospital tourniquet use in Operation Iraqi Freedom: Effect on Hemorrhage control. J Trauma 2008;64:S28–37.

7. Bellamy RF. The causes of death in conventional land warfare: implications for combat casualty care research. Mil Med 1984;149: 55–62.
8. Holcomb J, MacPhee M, Hetz S, Harris R, Pusateri A, Hess J. Efficacy of a dry fibrin sealant dressing for hemorrhage control after ballistic injury. Arch Surg 1998;133:32–5.
9. Calkins D, Snow C, Costello M, Bentley TB. Evaluation of possible battlefield tourniquet systems for the far-forward setting. Mil Med 2000;165:379–84.
10. Dorlac WC, DeBakey ME, Holcomb JB, et al. Mortality from isolated civilian penetrating extremity injury. J Trauma 2005;59: 217–22.
11. Walters TJ, Mabry RL. Issues related to the use of tourniquets on the battlefield. Mil Med 2005;170:770–5.
12. Wenke JC, Walters TJ, Greydanus DJ, Pusateri AE, Convertino VA. Physiological evaluation of the U.S. Army one-handed tourniquet. Mil Med 2005;170:776–81.
13. Walters TJ, Wenke JC, Kauvar DS, McManus JG, Holcomb JB, Baer DG. Effectiveness of self-applied tourniquets in human volunteers. Prehosp Emerg Care 2005;9:416–22.
14. NAEMT (National Association of Emergency Medical Technicians). PHTLS prehospital trauma life support: military version, 6th edn. St. Louis, MO: Mosby; 2007.
15. McManus J, Yershov AL, Ludwig D, et al. Radial pulse character relationships to systolic blood pressure and trauma outcomes. Prehosp Emerg Care 2005;9:423–8.
16. Gray HMW. The early treatment of war wounds. London: Oxford University Press; 1919.
17. Kirkup J. Fracture care of friend and foe during World War I. Aust N Z J Surg 2003;73:453–9.
18. Mattox KL, Bickell W, Pepe PE, Burch J, Feliciano D. Prospective MAST study in 911 patients. J Trauma 1989;29:1104–11; discussion 1111–2.
19. Walters T, Baer DG, Kauvar DS. A large animal fatal extremity hemorrhage model and evaluation of a polymeric dressing (fatal extremity hemorrhage). J Trauma 2006;61:1107–12.
20. Beecher HK. Early care of the seriously wounded man. JAMA 1951;145:193–200.
21. Beecher HK, Simeone FA, Burnett CH, Shapiro SL, Sullivan ER, Mallory TB. The internal state of the severely wounded man on entry to the most forward hospital. Surgery 1947;22:672–711.
22. Emerson CP, Ebert RV. A study of shock in battle casualties: measurements of the blood volume changes occurring in response to therapy. Ann Surg 1945;122:745–72.
23. Beebe G, DeBakey ME. Battle casualties: incidence, mortality and logistic considerations. Springfield, IL: Charles C Thomas; 1952.
24. Grant RT, Reeve EB. Observations on the general effects of injury in man: with special reference to wound shock (Medical Research Council Special Report Series No. 277). London: HM Stationery Office; 1951.
25. Lupkas RR Jr, Bellamy RF. Extremity injuries. In: Zajtchuk R, Grande CM, eds. Anesthesia and perioperative care of the combat casualty. Part IV of surgical combat casualty care in the textbook of military medicine series. Falls Church, Virginia: Office of the Surgeon General; 1995:499–520.
26. Mabry RL, Holcomb JB, Baker AM, et al. United States Army Rangers in Somalia: an analysis of combat casualties on an urban battlefield. J Trauma 2000;49:515–528; discussion 528–9.
27. Holcomb JB, McMullin NR, Pearse L, et al. Causes of death in U.S. special operations forces in the Global War on Terrorism: 2001–2004. Ann Surg 2007;245:986–91.
28. Kelly JF, Ritenour AE, McLaughlin DF, et al. Injury severity and causes of death from Operation Iraqi Freedom and Operation Enduring Freedom: 2003–2004 versus 2006. J Trauma 2008;64(2 Suppl):S21–6; discussion S26–7.
29. Lakstein D, Blumenfeld A, Sokolov T, et al. Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. J Trauma 2003;54(Suppl 5):S221–5.
30. Mucciarone JJ, Llewellyn CH, Wightman JM. Tactical combat casualty care in the assault on Punta Paitilla airfield. Mil Med 2006;171:687–90.
31. Wolf LH, Adkins TF. Tourniquet problems in war injuries. Bull U S Army Med Dep 1945;87:77–84.
32. Pillgram-Larsen J, Mellesmo S. Not a tourniquet, but compressive dressing. Experience from 68 traumatic amputations after injuries from mines [Norwegian; English abstract]. Tidsskr Nor Laegeforen 1992;112:2188–90.
33. Feltis JM. Surgical experience in a combat zone. Am J Surg 1970;119:275–8.
34. Böhler L. The treatment of fractures, vol 1. Tretter H, Luchini HB, Kreuz F, Russe OA, Bjornson RGB, trans. New York: Grune & Stratton; 1956.
35. Chisholm JJ. A manual of military surgery. Richmond, VA: West & Johnston; 1861.
36. Acheson EM, Kheirabadi BS, Deguzman R, Dick EJ Jr, Holcomb JB. Comparison of hemorrhage control agents applied to lethal extremity arterial hemorrhages in swine. J Trauma 2005;59:865–74; discussion 874–5.
37. Walsh MJ, Walker G. Seal! New York: Pocket Books; 1994.
38. Moore FA. Tourniquets: another adjunct in damage control? Ann Surg 2009;249:8–9.
39. Parker PJ, Clasper J. The military tourniquet. J R Army Med Corps 2007;153:10–2.
40. Medical Research Section Number 1. The wounded from Alamein: observations on wound shock and its treatment. Army Med Dep Bull 1943;(Suppl 7):1–32.

## ARTICLE SUMMARY

**1. Why is this topic important?**

Tourniquet use as first aid is lifesaving on the battlefield but controversial in civilian trauma, and recent military experiences are referents of lessons learned.

**2. What does this study attempt to show?**

Battle casualty survival rates remain high with emergency tourniquet use to stop limb bleeding, whereas morbidity rates remain low in comparison with prior reports.

**3. What are the key findings?**

Evidence indicates that when used for the right patient at the right time in the right way, emergency tourniquets save lives. Placing a tourniquet before the onset of shock improves the survival rate in exsanguinating limb injuries.

**4. How is patient care impacted?**

Tourniquet use for limb hemorrhage control on the battlefield increases survival time, permitting more effective resuscitation and yielding higher survival rates.