A New Main Squeeze? Tourniquets in EMS

Jeff Myers, D.O., Ed.M, NREMT-P, FAAEM
Department of Emergency Medicine
State University of New York at Buffalo
myersj@alum.rpi.edu
http://ems-ed.photoemsdoc.com/

History of tourniquet use

Tourniquet use can be traced back to the early Roman and Greek history. Much of the use of tourniquets was to reduce blood loss during amputations. It wasn't until approximately the 1600s that tourniquets were used on the battlefield for hemorrhage control. The early materials that were used were narrow bands of cloth tightened down around the limb, a fillet, which was a cloth used to tie back women's hair. In the early 1700s, Jean Louis Petit developed a screw type tourniquet that could be held in place on the limb to reduce slipping. Jean Louis Petit is also credited with coining the word tourniquet from the French word "tourner", which means "to turn."

In the late 1800s, Johann Friederich August von Esmarch, a German surgeon, developed a flat rubber bandage that could be stretched and provide a significant amount of circumferential compression around an extremity. The Esmarch Bandage is still used today by surgeons to exanguinate (drain all blood out of) a limb before surgery to prevent significant blood loss. In 1904, Harvey Cushing (the surgeon of Cushing Syndrome fame) developed a pneumatic tourniquet which allowed better pressure control and prevent overtightening.

During the U.S. Civil War, tourniquets were issued to soldiers for self use. Confederate Army General Albert Syndey Johnston died after being wounded in the popliteal artery while leading the Confederate charge on the Union army in the Battle of Shiloh, Tennessee in 1862. His tourniquet was in his pocket. Had he lived, the outcome of the U.S. Civil War may have been different!

Up to this point in time, very few complications were described. It was not until World War I where military physicians started describing complications they associated with tourniquet use. In the end, many of these complications were related to **prolonged tourniquet time** while the soldier waited in "no man's land" for evacuation. Army Physician Arnold Tuttle recognized that for some soldiers, a tourniquet was necessary to stop hemorrhage. He developed four recommendations regarding tourniquet use that are still taught today. Those four recommendations include:

- **Never cover the tourniquet**
- **Write "Tourniquet" on the medical tag**
- **If patient conscious, instruct them to tell everyone they meet a tourniquet has been applied.**
- **If the tourniquet is in place for greater than 6 hours, the limb is lost**

During World War II, a similar negative perception of tourniquet use was described. In a U.S. Army Medical Department Review found tourniquets were "...regularly misused," "applied unnecessarily," "kept unloosened for too long," "concealed with blankets or clothing." Based on these findings, it was recommended that if a tourniquet is placed, it should be loosed every **20 minutes**! As a later military physician wrote, this meant that soldiers exanguinated in increments of 20 minutes.

One interesting phenomenom was noted. In patients where the tourniquet was applied tight enough to stop venous bleeding but not arterial bleeding, it was noted that the hemorrhage was **worse** and in some cases hemorrhage stopped when the tourniquet was loosened. This occurred because arterial **in flow** was **unobstructed**, venous **outflow** was **occluded** and this produced a local increase in pressure in the extremity, leading to increased bleeding.

In both the Koren War and Vietnam War, there were many anecdotal observations made when tourniquets were used, however no hard data. In these anecdotal reports,

So why is all this attention being given to tourniquets? It was noted that in Vietnam that approximately **9**% of combat deaths were due to exanguination from an isolated extremity injury and was felt to be the **most common preventable battlefield death** affecting >2500 soldiers during the conflict. In the Global War on Terror, between **15-20** % of combat deaths are related to hemorrhage from a **compressible** site amenable to tourniquet use. In one study looking at civilian penetrating trauma in Houston, TX, there were 14 deaths in patients with isolated extremity penetrating trauma with 8 of those 14 felt on autopsy to be at a site amenable to tourniquet use (Dorlac 2005).

Pathophysiology

Much of the information we will discuss in this section is based on:

- **Surgical tourniquet studies**
- **Animal studies**

Does this directly apply to our situation? **In a limited way, yes**

We can divide this into the things that happen when a tourniquet is inflated, local changes that occur from the tourniquet and things that happen when a tourniquet is released and the limb reperfuses.

What Happens A Tourniquet is Placed? (systemic effects)

Cardiovascular

- **Increased** circulating volume (if the limb is exanginated before tourniquet is applied)
- **Increased** systemic vascular resistance
- **Increased** central venous & systolic pressure
- 30 – 60 min after tourniquet is applied:
  - **Increased** diastolic BP & HR
  - This is called: "**tourniquet pain**"

Hematologic:

- **Coagulation system activation** in limb
- **Catecholamine** release which adds to the systemic effects.

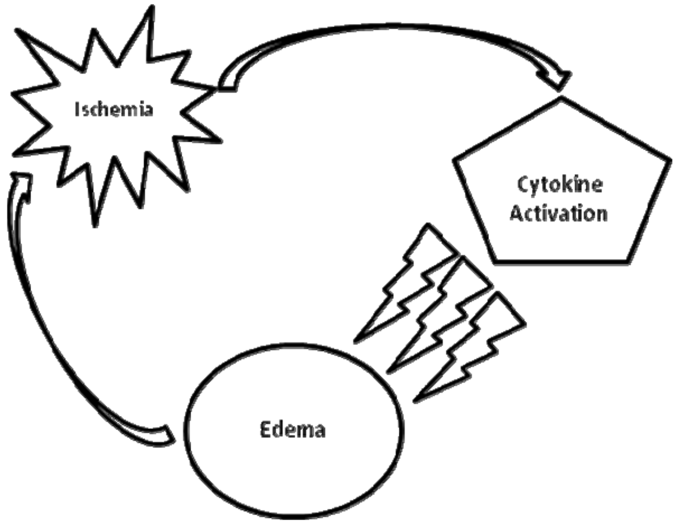
Temperature:

- **Transient increase** in body temperature (if limb esanguinated before tourniquet applied) due to the shift of warm blood to the core.

Local Effects

Nerve injury: Neuropraxia (nerve not transmitting inpulses after an injury) can range from mild **paresthesias** to full **paralysis**. It is most likely to occur in the **radial** nerve in the **arm** and the **sciatic** nerve in the **leg**. Fortunately, permanent damage is **rare** and typically occurs when the tourniquet has been on for **2 – 4 hours** and also related to **over pressure**.

Muscle Injury: The intracellular environment stays at baseline for the first **15** minutes after the tourniquet is placed. After that, the environment becomes steadily more **acidotic** for **up to 4** hours of ischemia. At this point the intracellular environment is severely **acidotic**, energy stores are **depleted** and there is an increase in **CO_2** and **lactate** production. When looking at the circulation, microvascular congestion occurs within the muscle which can worsen ischemia. This can be a vicious cycle that is difficult to break.



Arterial injury: While direct arterial injury is **rare** there is the risk of **plaque** rupture in vessels that are **artheromatous**. **Thrombosis** may also occur in the limb, further plugging the microcirculation up and decreasing the likelihood of reperfusion.

Skin injury: The tourniquet can produce direct trauma to the skin, including **pressure necrosis** and **friction burns**. The edges of the tourniquet should be rounded to avoid digging into the skin underneath the tourniquet.

What Happens A Tourniquet is Released? (systemic effects)

Cardiovascular: There is a **decrease** in CVP, SBP and VR (more so if the limb was exangunated prior to tourniquet application).

Respiratory: There is a transient **increase** in **$EtCO_2$** and in **respiratory rate** due to the release of **CO_2** in to the systemic circulation. If the patient is spontaneously breathing, this will normalize within **5 – 10 minutes**.

Cerebral: The **increase** in **CO_2** causes an **increase** in cerebral blood flow, which theoretically may **increase ICP and worsen head injury**. ***This is theoretical only and there is no clinical data to support this theory.***

Hematologic: Ischemia in the limb causes an activation of the **fibrinolytic** pathway, which potentially can cause **systemic** anticoagulation. Due to the stagnation of blood in the ischemic limb, there may also be release of **emboli** when the limb is reperfused.

Temperature: Is the limb was exanguinated before tourniquet inflation, there will be a **decrease in body** temperature after deflation.

Metabolic: On reperfusion of an ischemic limb, there is a transient increase in **potassium**, **lactate** and **oxygen consumption**. There is also a **decrease** in arterial pH, which means the patient will transiently become more **acidotic**. These changes occur after the tourniquet has been on for **between 1 and 2 hours** and the significance depends on the **length of time applied**. These return to normal in **30 minutes**.

Complications of tourniquet use

Local Complications

- **Direct skin damage**
- Muscle necrosis
  - Ischemia / edema cycle
  - May not reverse with reperfusion after **4 hours**
- **Compartment syndrome where the pressure increases in the muscular compartment due to swelling, compromising nerve and vascular function**
- **Permanent nerve and vessel injury are rare**
- Microscopic changes occur in rats' leg muscles after **three hours**

Duration to Damage In general, the length of time before permanent damage in an animal model:

Tissue Type	Duration
Muscle	4 hours
Nerve	8 hours
Fat	13 hours
Skin	24 hours
Bone	4 days

Reperfusion Complications

- These complications depend on the **duration of ischemia**
- Inflammatory cascade:
  - Set off by **procoagulants (compounds that promote coagulation) and waste products**
  - Effects from **leg greater than arm**
  - **Increase microvascular permeability (creates leaky capillaries systemically)**

- Systemic complications:
    - **Acute respiratory distress syndrome**
    - **Renal failure**
- Metabolic changes
    - **Hyperkalemia (high potassium)**
    - **Acidosis**
- Pain can be severe

Current literature (references at the end)

Tourniquets for Hemorrhage Control on Battlefield - 2003

This was a 4 year review Israeli Defense Force after they took an aggressive stance on tourniquet use. 550 soldiers injured with 125 deaths. None of the deaths were due to extremity hemorrhage. Tourniquets were used in 91 patients with an ischemia time of 83 ± 52 min. In the 91 patients, five had transient neurologic complications related to tourniquet usage. The ischemic time in these five patients was between 109 and 187 minutes.

Survival With Emergency Tourniquet Use - 2009

This was a single site, prospective observational study by U.S. Army at the Ibn Sina Hospital in Baghdad, Iraq while the author was deployed. Research assistants not involved in patient care recorded the information on all patients coming in with a tourniquet applied. There was three main conclusions from this study which were:

- Survival higher patients with tourniquet vs. patients without tourniquet
- Survival higher if normotensive before application
- Nerve palsies rare and transient

Practical Tourniquet Use - 2008

This had the same setting and time period as the Survival with Emergency Tourniquet study. They examined 428 tourniquet uses, 60% of which were prehospital and the remaining 40% were ED use. They found that the Emergency Medical Tourniquet (EMT) was 92% effective and the Combat Application Tourniquet (CAT) was 79% effective in stopping hemorrhage. The CAT performed better in the field and the EMT performed better in the ED. The authors found a transient nerve palsy in 4 patients (1.7%) and there were no amputations from the tourniquet. There was also no association found between ischemic time and various morbidities (clotting, renal failure, myonecrosis, rigor, pain) but there was an association between amputation and fasciotomy.

Tourniquets Revisited - 2009

In this study, the authors evaluated the use of three tourniquets (a sphygmamometer, ½ inch rubber surgical tubing, and a cloth / windlass setup) on occluding the pulse in the upper and lower extremities. The authors also tested the ability to apply enough pressure on the femoral pressure point to occlude the femoral artery. The authors found all tourniquets were successful. The use of the femoral pressure did not occlude the femoral pulse in any of the subjects used in the study.

Types of Tourniquets

Effectiveness of Self Applied Tourniquets in Human Volunteers

In this study, the authors tested 7 tourniquets that met U.S. Army Institute of Surgical Research requirements for tourniquets (stop bleeding 80% of the time, weigh less than 230 grams, strap width > 1inch [> 2 inch preferable], easy application in less than one minute, easy release and reapplication, no external power. Desirable qualities include: can use one handed in UE, can use in entrapped limb, protection from overtightening, large scale production cost <$25 each). The tourniquets were all self applied and tightened until either the Doppler pulse was lost or the pain was unbearable. Phase 1 of the study self was application to the distal thigh. Those tourniquets that worked 80% of the time moved to Phase 2 involved self application to the upper arm.

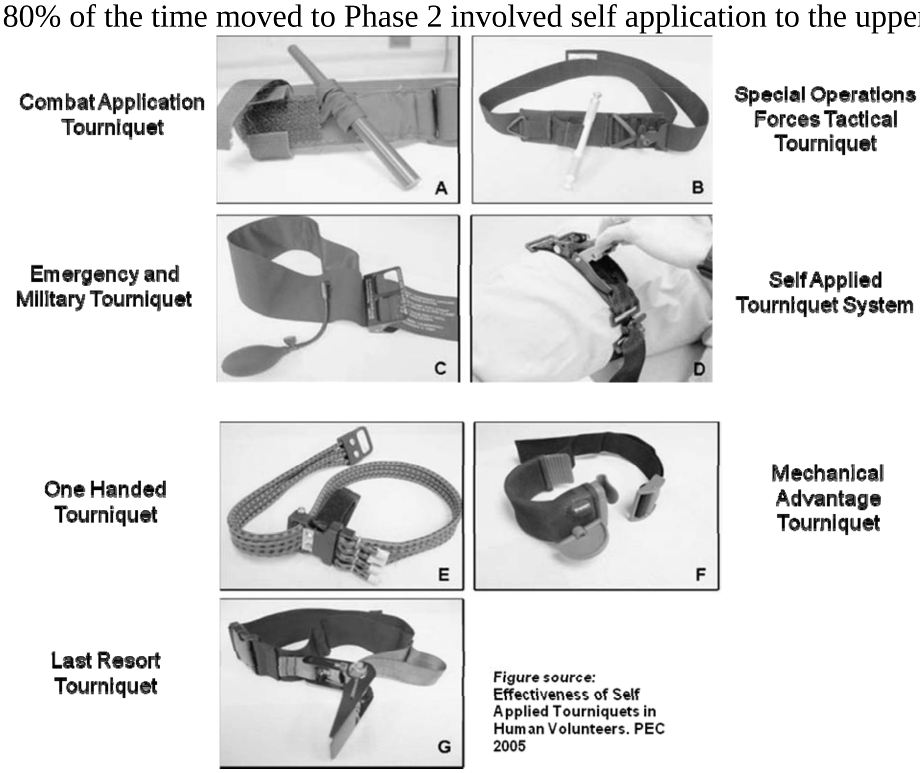


Figure source: Effectiveness of Self Applied Tourniquets in Human Volunteers. PEC 2005

Effectiveness:

TABLE 3. Results of Experiment I*

	CAT	SOFTT	EMT	MAT	LRT	SATS	H-Dyne
Percent effective	100	100	100	88	67	44	22
Number effective	18/18	18/18	18/18	14/16†	12/18	8/18	4/18
Failures (number of devices)							
Circumferential pain	n/a	n/a	n/a	1	2	2	4
Pinch pain	n/a	n/a	n/a	1	1	0	0
Slipping	n/a	n/a	n/a	0	3	0	5
Physical limitation	n/a	n/a	n/a	0	0	8	5

*See footnote of Table 1 for explanations of tourniquet abbreviations.
† $N = 16$ due to failure to replace and retest two devices following mechanical failures.

TABLE 4. Results of Experiment II*

	CAT	SOFTT	EMT	MAT
Percent effective	100	100	100	75
Number effective	12/12	12/12	12/12	9/12†

*See footnote of Table 1 for explanations of tourniquet abbreviations.
‡Failure in all cases was due to introlerable pinching pain.

Recommendations for tourniquet use

Civilian EMS Algorithms – Sources:

Doyle GS, Taillac PP. Tourniquets: a review of current use with proposals for expanded prehospital use. Prehospital Emergency Care 2008;12(2):241-256

Lee C, Porter KM, Hodgetts TJ. Tourniquet use in the civilian prehospital setting. Emergency Medical Journal 2008;24(8):584-587.

Taillac PP. Tourniquet first! Safe & rational protocols for prehospital tourniquet use. JEMS October 2008. Retrieved May 2009 from http://www.jems.com/resources/supplements/the_war_on_trauma/tourniquet_first.html

(The following articles reprinted from JEMS for educational purposes only)

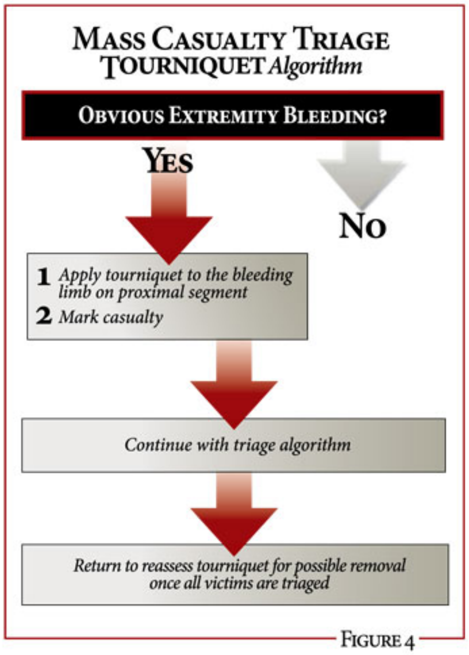


FIGURE 4

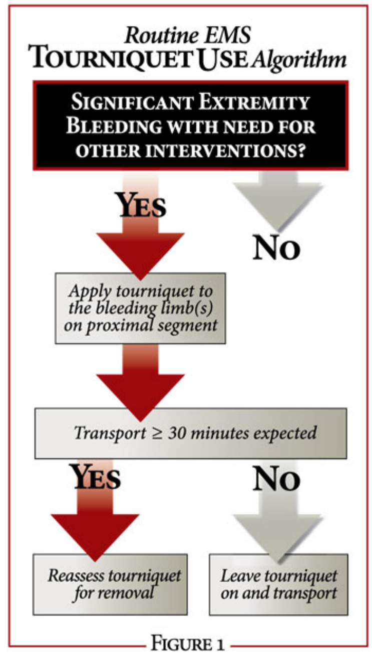


FIGURE 1

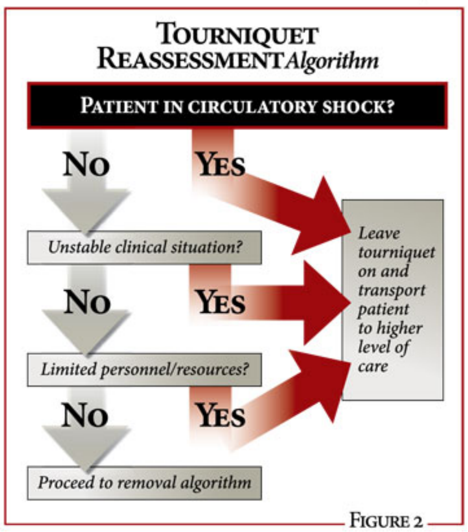


FIGURE 2

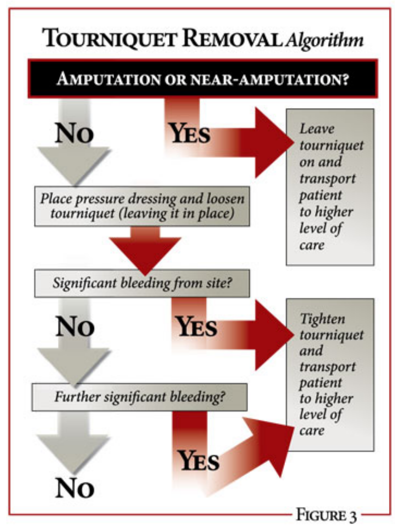


FIGURE 3

Tactical Medical Support

Follow TCCC recommendations:

- **Tourniquet first for major bleeding**
- **Reassess when not under fire**
- **Rapid evacuation**

Tourniquet Care

- **Keep limb uncovered** (Cooling extends tourniquet time)
- **Label triage tag and patient**

➢ **<u>If patient conscious, instruct them to tell everyone they contact they have a tourniquet</u>**

"[The tourniquet is] to be regarded with respect because of the damage it may cause, and with reverence because of the lives it undoubtedly saves. It is not to be used lightly in every case of a bleeding wound, but applied courageously when life is in danger"

– Hamilton Bailey, *Surgery of Modern Warfare,* 1941

References:

1. Bailey H. Surgery of modern warfare. Edinburgh: E&S Livingston 1941.
2. Beekley AC, Sebesta JA, Blackbourne LH, et al. Prehospital tourniquet use in operation Iraqui freedom: effect on hemorrhage control and outcomes. Journal of Trauma 2008;64(2 Supplement):S28-S37.
3. Bellamy RF. The causes of death in conventional land warfare: implications for combat casualty care research. Military Medicine 1984;149(2):55-62
4. Burris DG, FitzHarris JB, Holcomb JB, et al, eds. Emergency war surgery. Third United States revision. Washington, DC: United States Department of Defense, 2004:6.3-6.4
5. Dorlac WC, DeBakey ME, Holcomb JB, et al. Mortality from isolated civilian penetrating extremity injury. Journal of Trauma 2005;59(1):217-222.
6. Doyle GS, Taillac PP. Tourniquets: a review of current use with proposals for expanded prehospital use. Prehospital Emergency Care 2008;12(2):241-256.
7. Kam PC, Kavanagh R, Yoong FF. The arterial tourniquet: pathophysiological consequences and anesthetic implications. Anaesthesia 2001;56(6):534-545.
8. King RB, Filips D, Blitz S, Logsetty S. Evaluation of possible tourniquet systems for use in the Canadian forces. Journal of Trauma 2006;60(5):1061-1071.
9. Klenerman L. The tourniquet in surgery. Journal of Bone & Joint Surgery 1962;44B(4):937-943.
10. Kragh JF, Baer DG, Walters TJ. Extended (16 hour) tourniquet application after combat wounds: a case report and review of the literature. Journal of Orthopedic Surgery 2007;21(4):274-278
11. Kragh JF, Walters TJ, Baer DG, et al. Practical use of emergency tourniquets to stop bleeding in major limb trauma. Journal of Trauma 2008;64(2 Supplement)S38-S50.
12. Kragh JF, Walters TJ, Baer DG, et al. Survival with emergency tourniquet use to stop bleeding in major limb trauma. Annals of Surgery 2009;249(1):1-7.
13. Lakestein D, Blumenfeld A, Sokolov T, et al. Tourniquets for hemorrhage control on the battlefield: a 4-year accumulated experience. Journal of Trauma 2003;54(5):S221-S225
14. Lee C, Porter KM, Hodgetts TJ. Tourniquet use in the civilian prehospital setting. Emergency Medical Journal 2008;24(8):584-587.
15. Mabry RL. Tourniquet use on the battlefield. Military Medicine 2006;171(5):352-356
16. Marcus S. Catastrophic haemorrhage and emergency care. Emergency Nurse 2008;16(8):34-36.
17. Swan KG, Wright DS, Barbagiovanni SS, et al. Tourniquets revisited. Journal of Trauma 2009;66(3):672-675.
18. Tien HC, Jung V, Rizoli SB, Acharya SV, MacDonald JC. An evaluation of tactical combat casualty care interventions in a combat environment. Journal of Trauma 2008;207(2):174-178
19. Tuttle AD. Handbook for the medical soldier. New York William Wood and Company 1927 pp314-315.
20. Walters TJ, Mabry RL. Issues related to the use of tourniquets on the battlefield. Military Medicine 2005;170(9):770-775
21. Walters TJ, Wenke JC, Kauvar DS, et al. Effectiveness of self-applied tourniquets in human volunteers. Prehospital Emergency Care 2005;9(4):416-422.
22. Welling DR, Burris DG, Hutton JE, Minken SL, Rich NM. A balanced approach to tourniquet use: lessons learned and relearned. Journal of the American College of Surgeons 2006;203(1):106-115.