Collective Reviews

Tourniquets: A Review of Current Use with Proposals for Expanded Prehospital Use

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Abstract

The use of arterial tourniquets in prehospital emergency care has been fraught with controversy and superstition for many years despite the potential utility of these tools. This review examines this controversy in the context of the history of the tourniquet as well as its recent use in surgery and modern battlefield casualty care. Safe prehospital tourniquet use is widespread in the military and is based on sound physiologic data and clinical experience from the surgical use of tourniquets. The physiologic, pathophysiologic, and clinical underpinnings of safe tourniquet use are reviewed here, along with a discussion of alternatives to tourniquets. Prehospital settings in which tourniquets are useful include tactical emergency medical services (EMS) and other law enforcement environments as well as disaster and mass casualty incidents. Beyond this, we present arguments for tourniquet use in more routine EMS settings, in which it may be beneficial but has heretofore been considered inappropriate. Protocols that foster safe, effective prehospital tourniquet use in these settings are then presented. Finally, we discuss future directions in which tourniquet research and other initiatives will further enhance the safe, rational use of this potentially life-saving tool. **Key words:** tourniquet; hemorrhage; emergency medical services; disasters; hemostasis

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Introduction

Arterial tourniquets have a long and checkered history. Since their introduction, probably in ancient Roman times, their basic configuration has changed little to this day. They have been called both life saving and "an instrument of the [D]evil that sometimes saves a life."[1] Tourniquets have undergone a dramatic resurgence in popularity in the past decade, owing primarily to an emphasis on rapid hemostasis on the battlefield during recent wars.

Traditionally, tourniquet use has been ruled by the dictum *primum non nocere* or "first, do no harm." Tourniquets have been thought to be dangerous in the hands of prehospital care providers and have usually been seen as a technique of last resort for the emergency medical technician (EMT). This is the result of anecdotal experience from past wars when tourniquets were placed (sometimes unnecessarily) and left in place for extended periods, resulting in limb ischemia, muscle and nerve injury, gangrene, and amputations. However, recent experience with tourniquets in the hands of well-trained military medics, from both the United States and other countries, has resulted in renewed enthusiasm for the instrument in military emergency care. Lives are being saved on modern battlefields as a result of appropriate tourniquet use combined with rapid evacuation of casualties to definitive care. The parallels to modern emergency medical services (EMS) systems are obvious, and it is time to reconsider the tourniquet as a valuable and potentially lifesaving tool for the modern civilian EMT.

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Tourniquets, like all medical therapies, have certain dangers inherent in their use. These potential limitations and complications must be addressed prior to increased utilization in civilian EMS. Recent positive military experience with this instrument should not lead to irrational, unfettered tourniquet use. Rather, protocol-driven use by well-trained civilian EMTs would add a valuable weapon to the armamentarium of prehospital emergency providers, as they address difficult problems in controlling extremity hemorrhage.

Recent terrorist activities have served to emphasize the utility of the tourniquet in disaster settings. Disasters, whether man-induced or natural, may result in large numbers of bleeding individuals. Early in such an incident, a few rescue personnel may be required to triage and institute care for a large number of victims. There may not be enough providers to, for example, hold direct pressure on a heavily bleeding wound for long periods. In these circumstances, early utilization of a tourniquet by protocol may be appropriate. Indeed, a primary tourniquet approach, or "tourniquet first," may save lives by allowing the EMT to rapidly stop extremity hemorrhage, move on to other victims, and return later to reassess and possibly remove the tourniquet under circumstances that are more "stable." This is the model that is proving life saving in military field use in Iraq and Afghanistan, and should be considered for civilian EMT use as well.

We present a review of the medical literature focusing on the history, physiology, and complications of tourniquets, their current use, and alternatives to tourniquets for control of bleeding. We then discuss the use of tourniquets in civilian EMS care. Next, we show why EMTs should be facile in the safe use of these tools during situations not well addressed by current protocols. Finally, we argue that civilian EMS as well as law enforcement agencies should adopt expanded indications for tourniquet use under specific protocols.

History

Development and Early Uses[2]

The tourniquet arose from the need of battlefield surgeons to control bleeding during surgical amputations, with use being dated as far back as ancient Rome. Ambrose Pare (ca. 1510–1590) is credited with being the first to use the word *tourniquet*, as well as being among the first to record a recommendation for operative use of a tourniquet. He also performed the first-known modification on the tourniquet: A screw was placed over the main vessel of an extremity and tightened with a circumferential strap in place. Around the 17th century, William Fabry and Etienne Morel both used a *windlass*, wherein a stick is used to twist and thus further tighten a constricting band. Many modern designs feature a windlass to allow easy adjustment of tension.

Lister and Esmarch used tourniquets starting in the middle 19th century to introduce bloodless surgery. Technological advances led Cushing to abandon prior tourniquet designs and introduce a pneumatic tourniquet in 1904. This device made tourniquet application and removal easier, and pressure was more evenly applied to the limb than with prior versions. By the middle of the 20th century, use of tourniquets in extremity surgery to allow operation in a "dry field" was considered routine.

The Tourniquet in First-Aid

For many generations, tourniquet use in first aid has been controversial. Tourniquets have long been placed in first-aid kits, yet many surgeons who use them enthusiastically in operations have agreed with the tenet that there "is no place for the tourniquet as a first-aid measure."[2] Civilians were felt to be unable to use the instrument safely or effectively, and there has been previous military experience of harm done by inappropriate tourniquet use on bleeding limbs.[3] The most recent American Heart Association and American Red Cross First Aid manuals reflect this philosophy. While recognizing the pivotal role of hemorrhage control, the 2005 First Aid Guidelines of the National First Aid Science Advisory Board recommends only direct pressure and compression dressings (using an elastic bandage) to stop bleeding before EMS providers arrive.[4]

Military Considerations

The tourniquet has a rich historical tradition in military medicine, in contrast to civilian EMS use. Tourniquets were issued in Civil War surgical sets,[5] and the failure to apply one to a wounded Confederate Army general may have affected the outcome of that war and thus the course of U.S. history.[6] Paradoxically, it is perhaps from the same war that initial ambivalence to tourniquets arose: Prolonged time from tourniquet placement to definitive care often resulted in severe ischemic complications. This caused some surgeons of the day to argue that it was safer to allow continued bleeding than use a tourniquet to stop it.[7]

Tourniquets have long been standard issue in military medics' kits, yet there has been reluctance to use them in all but the direst of circumstances. In the 1960s, there were even efforts to have them removed from medical kits and deleted from the training curricula of military medics.[2]

Mabry describes a cycle wherein the tourniquet is initially welcomed by the military but soon falls out of favor due to perceived misuse, while many who might have been saved die of potentially controllable hemorrhage.[7] This cycle was repeated until analysis of mortality data from the Vietnam conflict led to renewed interest in the use of the tourniquet. This analysis suggested that a sizeable proportion of combat fatalities could have been averted by use of a tourniquet. In one report, it was estimated that 105 (38%) of

277 soldiers who died from extremity artery bleeding might have been saved by proper, timely tourniquet application.[8]

Recent experience has reinforced this trend toward more liberal military usage of tourniquets.[9–11] Modern combat results in high rates of extremity trauma. This fact, combined with the recognition that many who died of combat-inflicted wounds might have survived if a tourniquet had been used to arrest exsanguinations, forms the rationale for use of a tourniquet under modern combat conditions.[12] Sebesta, who has detailed his experiences as a surgeon in an Army Combat Support Hospital (CSH), states "tourniquets are an essential therapy based on recent experience in Iraq."[9]

This rationale is further reinforced by the circumstances under which much of the prehospital care is provided during a military conflict: Hostile action by adversaries, unfavorable environmental conditions, frequently prolonged transport to advanced care, austere logistics, and multiple casualties with limited triage and treatment manpower all support the expedient use of tourniquets on the battlefield. It is to be noted that these conditions are occasionally, if infrequently, experienced in civilian EMS settings as well.

The U.S. Army and Marine Corps both now issue tourniquets to individual soldiers and marines in their Individual First Aid Kits (IFAK) and train them in their proper use.[13,14] The Army prehospital trauma life support (PHTLS) mnemonic is now "MARCH" (Massive bleeding, Airway, Respirations, Circulation, and Head Injury) rather than "ABC" (Airway, Breathing, and Circulation), recognizing that massive hemorrhage on the battlefield is the primary treatable threat to survival and must be quickly arrested.[9]

Still, despite these changes, more than 50% of the deaths from isolated extremity hemorrhage were potentially preventable by correct tourniquet application, according to one report from the Iraq conflict.[11] It is not known how many patients with multisystem injuries had tourniquets placed nor if this intervention improved or worsened outcome.[15] Further reviews of battlefield tourniquet use will better document these results.

Civilian EMS Usage

There has been a movement toward liberalization of tourniquet use in civilian EMS systems, but this remains controversial. Most systems still employ the tourniquet as a technique of last resort, using protocols that recommend direct pressure, pressure dressings, pressure points, elevation, and cold application as primary treatments for severe extremity hemorrhage. Of these, only direct pressure can be supported based on available evidence.[4] The most recent National Association for EMS Physicians (NAEMSP) consensus statement on wound care for delayed or prolonged transport recommends the use of tourniquets *only* in cases of amputation.[16]

Despite extensive experience with tourniquets in the military medical services of the United States and other countries, recent civilian EMS teaching has not fully accepted this potentially life-saving instrument.[17] Indeed, many EMS systems do not allow their crews to carry tourniquets. Unfortunately, this can lead to circumstances in which a tourniquet is required and may have to be improvised. Improvised tourniquets are less likely to be effective[10] and may be more prone to neurovascular complications.

The positive experience with tourniquets on the battlefield holds promise for civilian EMS trauma care: Modern military protocols for tourniquet use could easily be incorporated into civilian EMS systems.

Physiology, Complications, and Safe Use of Tourniquets

Physiology

Arterial tourniquets work by compressing muscle and other tissues surrounding extremity arteries that, in turn, collapse the lumina of these arteries and thereby arrest flow distal to the tourniquet. The tension or force needed in order for a tourniquet to compress the artery is dependent on the size of the extremity as well as the width of the tourniquet. In general, larger circumference of an extremity correlates with higher required tension.[18] Wider tourniquets typically are more effective at stopping arterial flow at a given tension than narrow tourniquets.[19]

Complications

Tourniquet use, which is well accepted as a technique for bloodless extremity surgery, has been associated with local and systemic complications (see Table 1).

TABLE 1. Potential Complications of Use of Tourniquets[a]

Local	Systemic
Postoperative swelling and stiffness	Increased central venous pressure
Delay in recovery of muscle power	Arterial hypertension
Compression neuropraxia	Cardiorespiratory decompensation
Wound hematoma	Cerebral infarction
Wound infection	Alterations in acid-base balance
Direct vascular injury	Rhabdomyolysis
Bone and soft-tissue necrosis	Deep venous thrombosis
Compartment syndrome	Tourniquet pain
	Systemic inflammatory response syndrome[b]
	Fibrinolysis[c]

Complications of operative tourniquets that have been reported in the surgical literature are presented here.
[a] Ref. 20.
[b] Ref. 31.
[c] Ref. 32.

Early surgical use of tourniquets led to the recognition that improper tourniquet design or prolonged tourniquet application (longer than 1.5 to two hours) could lead to muscle, nerve, and vascular injuries, resulting in a syndrome known as *tourniquet palsy* or *tourniquet paralysis*. Additionally, irreversible ischemic damage to limbs is known to occur in cases where a tourniquet had been left in place for longer than six hours; amputation of the limb above the level of the tourniquet was recommended in these circumstances and still remains a surgical dictum.[2]

Tourniquet time (i.e., the total time during which arterial flow beyond the instrument can be safely interrupted) is an issue of controversy. Evidence from animal studies shows that even minutes of tourniquet use will lead to changes in muscle and nerve physiology as well as systemic effects. These studies demonstrated that after one hour, there was no evidence of muscle damage, while two hours of ischemia led to elevated levels of both lactic acid and CPK, suggesting muscle damage was occurring.[21]

Most surgical guidelines recommend, and clinical studies support, no more than 60–90 minutes of operative tourniquet time in order to safely use this technique. Two hours of tourniquet time is a "useful guideline" for an upper limit.[20] Patients with advanced age, vascular diseases, and traumatic injuries are at higher risk for complications, including nerve and muscle injury. Nerve injuries have been reported after only 30 minutes of tourniquet time. Muscle, especially that directly under the tourniquet, has shown damage after one hour, though actual myonecrosis seems to occur only after three hours.[22] *Post-tourniquet syndrome* (comprising weakness, paresthesias, pallor, and stiffness) is common but seems to resolve after about three weeks.[23]

Recent military experience supports the safety of these short tourniquet times in prehospital patients.[9–11] Chambers et al. reported limb salvage in 11 of 14 (79%) of patients with arterial injuries despite total tourniquet times averaging two hours.[24]

All known complications of tourniquets seem to worsen with prolonged tourniquet time. Unfortunately, tradition has held that tourniquets, once placed, should be left on until removed by a physician. This tenet likely arose from the recognition that repetitively loosening and retightening a tourniquet exacerbates blood loss. While such "reperfusion intervals" are controversial and discussed in more detail below, our proposed protocol (and current military doctrine) allows for reevaluation of the need for, and possible removal of, a tourniquet by EMTs prior to reaching the hospital.

Tourniquet use may also result in venous complications, including worsened venous bleeding and venous thromboembolism (VTE). One major criticism of tourniquets is that, if not properly applied, tourniquets can actually increase bleeding by occluding venous return while not completely arresting arterial inflow. Thrombosis could occur due to venous stasis during tourniquet use. Subsequent embolization of the clot(s) to the pulmonary circulation could then occur, either before or after tourniquet removal. The role of tourniquets in inducing venous thrombosis and pulmonary embolism is not clear. VTE has been reported to increase with tourniquet use in surgery; however, others have suggested that this complication is a result of surgery itself, not merely of tourniquet use.[25–27]

Elastic or compression dressings can be similarly criticized, as both may increase bleeding and promote venous stasis and VTE. A further drawback is that if placed too zealously, they can become an unrecognized arterial tourniquet.

Compartment syndrome has been a reported complication of tourniquet use. In most cases, this is felt to result from the injury necessitating tourniquet use, rather than the tourniquet itself, except in prolonged tourniquet-induced ischemia (more than three hours) or excessively high tourniquet pressures.[23]

Systemic acid-base changes may result from release of a tourniquet in place for an extended period of time. Limb ischemia results in lactic acidosis of tissues distal to the tourniquet. After release of the tourniquet, reperfusion of the extremity carries this acid and free radicals into the central circulation, a syndrome labeled *ischemia-perfusion injury*. Hyperkalemia and systemic acidosis may result in cardiac arrhythmias, among other problems. Clinical experience on the systemic metabolic effects of tourniquet release is inconsistent, and may vary with anesthetic technique. One study showed no such results after one to three hours of tourniquet time in a sample of elderly orthopedic surgery patients,[28] while a second showed that arterial pH, P_aO_2, P_aCO_2, lactate, and potassium changed significantly after tourniquet release.[29]

Hypertension and increased central venous pressure following operative tourniquet application are well-documented, but may be related to surgical practice: elevation and compression of the extremity to create a bloodless field results in autotransfusion of extremity blood into the central circulation.[30] Such an event is not likely to occur with field use of the tourniquet.

Other systemic changes, such as creation of a systemic inflammatory response and increased fibrinolytic activity, seem to be transient and are not known to be clinically significant.[31,32]

Pain from tourniquet use is a major concern. Some have stated that tourniquets can cause "excruciating pain"[33] despite proper application. In one report, however, awake, nonanesthetized volunteers who had tourniquets placed and inflated to 100 mmHg above their systolic blood pressure tolerated the instruments for 25 minutes on their forearms and 18 minutes on the upper arm.[34] It is not clear if a lower pressure, sufficient only to arrest bleeding, would be tolerated longer. Lower extremities, perhaps due to increased circumference, have higher average times of pain tolerance, around 30 minutes.[35] It is clear, however, that most awake patients on whom a tourniquet is used will require medication for pain control.[36]

Safe Prehospital Use

Safe prehospital tourniquet use depends on a number of factors. Underlying all safe prehospital tourniquet use are conservative and specific protocols defining indications, application and removal techniques, and application times. As always, regular training in protocols for prehospital providers is crucial. The outline of safe, effective protocols for prehospital tourniquet use can be extrapolated from both widespread surgical use and recent military experience.

The fundamental factors relating to safe tourniquet use are: tourniquet design, placement location, tourniquet tightness, and tourniquet time.

In terms of tourniquet design, it is well known that wider tourniquets with rounded, rather than sharp, edges are best in terms of limiting damage to underlying structures. The tourniquet should be made of a uniform, smooth material, as those with wire reinforcements are known to predispose to direct vascular injury due to unequal application of pressure under the wires.[37] As a pneumatic tourniquet, a blood pressure cuff is theoretically ideal, as it provides uniform pressure over a wide area. Its practical use, however, is somewhat limited by its size and weight, as well as its inability to maintain high pressures for prolonged periods. It is also difficult to apply securely to a short residual stump in the case of a traumatic amputation.

Most operative manuals recommend tourniquet placement on the thickest portion of the limb in order to maximize the tissue through which pressure is exerted and minimize the pressure require to stop arterial flow and thus the risk to underlying skin, muscle, nerves, and vessels. This may also limit the pain associated with tourniquet use, though some studies contradict this.[33,38]

EMS providers, however, have traditionally been trained to place the tourniquet just above the injury, while avoiding placement over a joint.[39] This more distal placement recommendation probably arises from concerns about the need for an amputation after definitive care is reached. The goal is to preserve as much limb length as possible. However, with proper tourniquet design and limited tourniquet time, a more proximal placement of the largest portion of the extremity is preferred because of speed of application, minimization of pressure injury to underlying tissues, and the possibility that multiple distal bleeding sites exist.

When applying a tourniquet, the lowest effective pressure should be used in order to minimize subsequent ischemic complications: A tourniquet must be tightened only to the pressure required to arrest hemorrhage.

There is no rationale for using an occlusive tourniquet as a high-pressure dressing by placing it directly over a wound dressing, as it will not effectively stem arterial inflow to the wound in this location. Used nonocclusively, however, a tourniquet could effectively be used to augment a pressure dressing and hold it tightly in place, as suggested in a recent review of tourniquet use.[40]

Some have attempted to prolong tourniquet time by use of "reperfusion intervals." Although taught in some popular wilderness first-aid manuals,[41,42] these intervals are not practical in prehospital scenarios. These have been shown clinically to reduce complications only if perfusion is restored for 30 minutes or more.[43] Therefore, to be effective at reducing ischemic complications, they would likely also allow slow exsanguination. An interesting suggestion designed to lessen injury to tissues directly under the device is to use two adjacent tourniquets, alternately employing one then the other.[44]

All tourniquet usage must be well documented, then communicated on transfer of care. This minimizes the likelihood that a tourniquet will be overlooked by subsequent care providers and inadvertently left on for a prolonged period. Time of application must be recorded, either on the triage tag or physically written on the skin of the victim. The forehead is suggested as a prominent location. Triage cards should clearly annotate that a victim is wearing a tourniquet and the time of placement, as does the current DD Form 1380 *Field Medical Card*. One early advocate of the tourniquet recommended that casualties who are conscious be instructed to tell everyone with whom they come into contact that they have a tourniquet in place.[45] For the same reason, tourniquets should never be covered. There is evidence that cooling the extremity distal to the tourniquet may reduce complications.[46] A blanket placed over a tourniquet may be doubly dangerous, both warming the ischemic extremity and obscuring the tourniquet. The extremity is probably best left uncovered, except in temperatures where there is risk of direct cold injury. If available, a brightly colored marker may be placed at the tourniquet location as well.

The tourniquet should ideally be manufactured for its purpose. Improvised tourniquets will tend to apply pressure unevenly and often have sharp edges, increasing the risk of underlying tissue injury. Examples of suboptimal improvised tourniquets include belts and similar straps, which can entrap skin and directly cause injury. Cravats (i.e., triangular bandages) or elastic dressings (i.e., ACE® bandages) can bunch when twisted with a windlass.[47] Although these improvised options are frequently taught in first-aid manuals, they should be avoided unless no other options are available to arrest hemorrhage.

Finally, and most critically, tourniquet time must be minimized. In most cases, this will mean transporting the patient expeditiously to a higher level of care. Informing the transportation officer at a mass casualty event of "tourniqueted" patients may allow these patients to have higher priority for transport to hospital. In our protocol, no patient with a tourniquet will receive a triage code less acute than "yellow." In addition, specific protocols can be utilized to remove tourniquets that, upon reassessment at a later time, may no longer be needed to control bleeding.

Alternatives to the Tourniquet

Pressure Dressings

Pressure dressings are adequate to stop most cases of hemorrhage, whether it occurs from the extremities or other parts of the body. One commercially available bandage already in use by the military for this purpose is the "Israeli dressing." Other compression dressings can be improvised with large amounts of gauze and an elastic bandage that is wrapped around the wounded limb, as described in a recent PHTLS manual.[39] These bandages work on the principle of providing compression to reduce the flow of blood through damaged vessels (primarily capillaries and veins) while providing a "scaffold" on which blood can clot. As mentioned previously, a carefully placed tourniquet could also be utilized to tightly compress a bandage and act as a pressure dressing, but only if it is not so tight as to occlude arterial inflow or to increase distal venous bleeding.

Experience with pressure dressings shows that they work well in trained hands, stopping all "moderate bleeding" and most "profuse bleeding" (81%), according to one study. A tourniquet was required to stop one case with "profuse bleeding."[48]

A major drawback of this type of dressing is that they take time and often more than "one set of hands" to apply properly. They must also be reassessed frequently to ensure that bleeding has, in fact, been arrested, which requires access to the site of the dressing as well as a light source. It is foreseeable that circumstances may arise in which one or both of these are not available, and time and personnel are needed to perform these assessments. In contrast, once placed and tightened to arrest bleeding, modern tourniquets are highly unlikely to lose effectiveness. After resuscitation, however, they may require retightening if the victim's blood pressure increases sufficiently to allow distal flow.[36]

Self-application of an adequate pressure dressing can be extremely difficult, if not impossible, and is certainly time-consuming. Modern tourniquets, including the model preferred by the military, have been specifically designed for one-handed self-pplication. The goal is rapid self-application in order to allow the victim to continue the mission, if physically able to do so.

Finally, pressure dressings may be difficult or impossible to secure to limbs that have sustained partial or complete amputation.

In short, pressure dressings are excellent instruments to control most causes of hemorrhage, but are not easily adaptable to circumstances in which there are limitations on time and personnel, after amputation, or when self-application is required. In these scenarios, a tourniquet is much more easily and effectively used.

Topical Hemostatic Agents

Topical hemostatic agents were developed in response to the recognition that uncontrolled hemorrhage is the major source of preventable mortality in combat settings. Several have been deployed with U.S. forces in recent combat actions around the world[49] and their successes and shortfalls reported in the medical literature.[50–52]

Although they may be useful adjuncts, these agents do not have the same simplicity and effectiveness of pressure dressings or tourniquets. Experience in animal models has shown that many agents simply do not work quickly or well enough to stop brisk bleeding.[51] HemCon is a gauze dressing impregnated with chitosan (extracted from shrimp shells) that assists in clotting. Although this dressing was felt to work well for hemostasis on war-wounded in Iraq, the majority of these were venous bleeds.[52] Another agent, QuikClot, was shown to cause burns and other soft-tissue complications in nearby tissue when used in its initially marketed powder form.[51] A newer formulation reportedly does not have this complication.

Small, deeply penetrating wounds like those produced by missiles are also problematic for topical hemostatic agents, which must either be trimmed or otherwise altered and placed in wounds in direct contact with bleeding sites to ensure hemostasis. In the case of the HemCon dressing, even large "cavitational" wounds required that the dressing be placed under direct vision, directly on the bleeding site, for the dressing to be most effective.[51] Finally, it should be noted that, with the exception of QuikClot, these are expensive, perishable agents. These issues all limit these agents to being useful adjuncts, rather than primary treatments, for extremity hemorrhage in disaster and other EMS settings.[50]

Systemic Hemostatic Agents

Hemostatic agents that improve coagulation, especially in hypothermic, coagulopathic, and acidotic multitrauma patients, have been in development and preliminary use in the recent past. Factor VIIa concentrate, for example, has been extensively used by surgical teams in Afghanistan and Iraq with favorable results.[9,53]

Little, if any, specific prehospital use of these agents has been reported.[54] In most cases, these agents have been used in patients with cavitary or visceral rather than external hemorrhage, and their applicability in extremity injuries is not known. In addition, current agents are prohibitively expensive for routine EMS and disaster use.

Recommendations for Tourniquet Use in Civilian EMS Systems

Tactical EMS and Police Officers

Tactical EMS (TEMS) providers, usually paramedics, support special weapons and tactics (SWAT) or special operations teams found in many civilian law enforcement agencies, from the municipal to the federal level. Most of these personnel come from a background of civilian EMS agencies and are steeped in the tradition of tourniquet avoidance. Current trends in law enforcement, particularly as they impact on SWAT operations, demand that we reevaluate the appropriateness of applying typical civilian EMS practices to law enforcement and TEMS environments. Civilian firearms-related incidents are becoming more and more like military operations.

Military-style weapons with large, high-velocity bullets have proliferated in recent years as weapons of choice among gangs, narcotics traffickers, and terrorist groups. No longer can law enforcement officers assume that they can easily "outgun" the suspects they are charged with apprehending.

Coincident with the change in the nature of these weapons is a change in the wounds and injuries resulting from their use. Like today's military, police officers typically wear body armor as a means of mitigating some of the increased risk they now face from heavily armed suspects. While helping reduce risk of death or grave injury from torso wounds, these vests have not reduced the burden of extremity injury as a potential cause of death in urban conflicts.[55]

In 1997, a pair of heavily armed bank robbers wearing body armor held Los Angeles police at bay until being fatally wounded. One responding officer shot in the thigh reportedly lost an estimated 40% of his total volume of blood, lost consciousness, and nearly died. Had he had access to a tourniquet, he might have been able to stop the bleeding himself and perhaps even continue to support the mission at hand.

The weapons used by police in responding to violent criminals could also create circumstances in which the tourniquet may prove beneficial. A medical examiner stated one suspect in the event described above died due to thigh wounds that caused exsanguination. Civilian EMS personnel were unable or unwilling to enter the scene.[56] The suspect's family sued the city of Los Angeles for this "notorious" inattention. Application of a tourniquet under these circumstances, perhaps even one given to the victim with instructions on how to place it, may have saved the life of this person.[57]

Beyond firearms, the use of explosives by terrorists and other elements is blurring the distinctions between military conflict and civilian crime. ATF and FBI statistics show that, even before the Oklahoma City bombings and 9/11 made terrorism more of a concern in the United States, there were large numbers of bombings for criminal and "entertainment" purposes.[58,59]

The traditional civilian model of trauma care exemplified by the "golden hour" concept will blur along with these changes. Deaths from military-style weapons and explosives conform to a different distribution of time of death when compared with the more typical civilian trauma experience. Most deaths occur very early, prior to hospital care. Many of these are due to exsanguination[60] and extremity hemorrhage is the leading cause of death in potentially salvageable victims.[12]

These considerations all argue for training and equipping police officers for tourniquet use on themselves or others, much as the military has done for its front-line troops. While widespread tourniquet availability among "lay providers" may make some uneasy, we note that individual soldiers have been able to use the instrument successfully on themselves or wounded colleagues.[15] In addition, there is justification for allowing trained police officers to use tourniquets on civilian victims, as part of basic first aid. There is already widespread experience with police personnel delivering first-responder care, including cardiac care via the use of AEDs. Police officers have also been trained to perform triage at mass casualty incidents.[61] Initial concerns about acceptance of these roles by police officers[62] have not been borne out.[63]

Disaster Situations/Mass Casualty Triage

Isolated extremity injury causing exsanguination also occurs in civilian EMS practice. Preventable deaths due to failure of prehospital personnel and hospital providers to stop limb hemorrhage have been reported. In one study, 57% of those dying in metropolitan Houston due to isolated penetrating extremity trauma had bleeding sites amenable to tourniquet therapy.[64]

The events of 9/11/2001 showed that global terrorism can now be a local occurrence. With terrorism come weapons of mass effect. While biological (such as anthrax), chemical, and nuclear/radiologic weapon threats have received great focus, attacks using conventional weapons such as explosives and firearms still prevail as "the most common type of terrorist attacks in modern history."[65]

Casualty data and mortality trends from civil unrest, especially bombings, have bolstered the arguments for use of tourniquets in prehospital care: penetrating extremity injuries occur in about half of the severely injured.[66] This increase in extremity trauma is not limited to adults: Pediatric victims of violence also have higher rates of penetrating extremity injury than do child victims of "non-terror-related injuries."[67]

Explosives, via primary, secondary and tertiary blast effects, induce amputations, partial amputations, and penetrating wounds of the extremities in bystanders. Recent experiences in Lebanon,[68] Palestine,[69] Israel,[65] Kosovo,[70] Bali,[71] Madrid,[72] London,[73] and other settings have shown that there can be large numbers of victims with complex injuries, including mangled extremities, amputations, partial amputations, and missile injuries, in addition to head, spine, and visceral injuries.

It has been noted that these types of events combine the severe mechanisms of injury typically associated with military combat with the short intervals from injury to rapid transport and definitive treatment, which are more characteristic of the civilian trauma experience.[74] Under these circumstances, many victims need only very simple interventions from EMS providers: The use of tourniquets for brief periods to limit blood loss and expedite transport would be a rational, and possibly life-saving, intervention.

Control of bleeding is beneficial to patient survival.[75] Indeed, even in those who survive despite massive hemorrhage, reducing blood loss and thereby preserving vital oxygen-carrying capacity will lessen complications, such as the adult respiratory distress syndrome and multisystem organ failure. A tourniquet that completely arrests hemorrhage before resuscitation will maximize preservation of red blood cells.

A triage officer or EMS crew responding to mass casualty event must be able to act quickly with simple interventions in order to maximize victim survival. Taking the time (and personnel) to apply pressure dressings could impair the smooth implementation of triage algorithms in mass casualty situations. As an example, the most recent PHTLS handbook recommends 10–15 minutes of direct digital pressure to stop bleeding.[39] Clearly, this will be impractical or impossible in many disaster situations. In addition to penetrating extremity injuries, head and torso injuries may also demand immediate stabilization. Multiple serious injuries make time-consuming hemorrhage control measures an unaffordable luxury.

In these circumstances, EMS personnel must have access to, and training with, arterial tourniquets. A protocol that allows tourniquets to be used as a first, rather than last, resort is imperative. Placing a tourniquet on a bleeding extremity, noting the time of placement, and moving on to the next victim will allow providers to immediately stop bleeding that would otherwise contribute to hemorrhagic shock and may even cause fatality. Advanced Trauma Life Support (ATLS) training now acknowledges the need to stop "obvious external bleeding" during the primary survey.[76]

Once all victims have been triaged, or more help has arrived, prehospital personnel can return to those victims who have tourniquets in place. Wounds can then be reassessed and tourniquets possibly removed and replaced with pressure dressings. Although this approach seems to violate the traditional teaching that a tourniquet placed in the field must be left on until the victim reaches a hospital, there are circumstances in which this approach is reasonable, for example, if delayed or prolonged transport is anticipated. Algorithms have been developed for primary tourniquet placement and reevaluation with conversion to nontourniquet-based hemostasis[10,77] and successfully used in 76% of cases.[10]

Tourniquets are simple devices. Nonmedical safety personnel as well as lay people (such as "walking wounded") can be quickly trained to apply these devices safely and effectively. Victims themselves could even effectively use some types of tourniquets on their own wounded extremities.[78] Data from Canadian studies show that most commercial tourniquet models can be applied effectively in under 30–40 seconds.[79] Providers can be easily taught to quickly and effectively apply tourniquets. Life-support courses have been changing to simplify techniques for responders. Tourniquets should be taught as an adjunct to standard hemorrhage control techniques. Pressure points and elevation are commonly taught to lay persons. These techniques are arguably no simpler than tourniquet application and, unlike tourniquets, are of unproven benefit.[4]

Routine EMS Usage

Tourniquets can also be useful in cases involving single patients, but only if EMS providers have access to appropriate protocols, training, and equipment. They must have familiarity with the indications and techniques for the use of tourniquets in order to avoid an inappropriate (and historically based) fear of these instruments. Tourniquets are naturally compatible with a "scoop and run" approach to trauma care in which simple, rapid, and potentially life-saving interventions are combined with expeditious transport to definitive care.

The use of a tourniquet to control extremity bleeding maximizes the ability of EMS providers to resuscitate a hypotensive patient by "stopping the leak." Ongoing extremity bleeding will hinder adequate resuscitation. Intravenous (IV) fluid infusions will simply dilute valuable oxygen-carrying hemoglobin and clotting factors.[63,80]

A "tourniquet first" approach to the single, multiply injured patient allows the provider to immediately stop obvious extremity bleeding, allowing attention to be then turned to more time-consuming airway or breathing priorities. After these are attended to, attention can be directed to the bleeding extremity, with possible exchange of the tourniquet for a pressure dressing.

Transportation of prehospital patients is also facilitated by placement of tourniquets. Personnel do not have to maintain digital pressure or frequently check and reinforce dressings. This frees the provider to pay more attention to maintenance of vital signs, to obtain IV access, or to complete a secondary survey en route to the hospital. In austere circumstances such as wilderness settings, disasters, or hostile-fire situations, this advantage is made even more significant as providers are freed to perform other roles or to care for multiple patients.

We also know that field-improvised tourniquets may not be as safe as commercially manufactured tourniquets (bandage/windlass combinations can "bunch" into a constricting band[47]) and are frequently ineffective.[10] It is better to have equipment, specifically designed for the task of controlling catastrophic bleeding in the hands of personnel well-trained in its use than to ask them to fabricate crude devices under stressful and possibly physically threatening circumstances.

Protocols for Prehospital Tourniquet Use for Severe Extremity Hemorrhage

Indications

Table 2 presents proposed indications for prehospital tourniquet use, including routine EMS use in nondisaster settings. The goal of tourniquet use as presented here is to allow prehospital personnel to safely, rapidly, and effectively stop extremity hemorrhage, thus freeing the rescuer to triage and treat other patients or rapidly address other emergent issues on a solitary patient. These principles are relevant to both mass casualty situations and the care of a single patient. They are intended to maximize the rescuer's efficiency and enhance the safety of both patient and rescuer during triage and treatment.

TABLE 2. Indications for Tourniquet Use in Eemergency Medical Services (EMS) and other Prehospital Settings

Amputation
Failure to stop bleeding with pressure dressing(s)
Injury does not allow control of bleeding with pressure dressing(s)
Significant[a] extremity hemorrhage in the face of any or all of:
Need for airway management
Need for breathing support
Circulatory shock
Need for other emergent interventions or assessment
Bleeding from multiple locations
Impaled foreign body with ongoing extremity bleeding
Under fire or other dangerous situation for responding caregivers
Total darkness or other adverse environmental factors
Mass casualty event[b]

Proposed indications for tourniquet use in EMS.
[a] "Significant" as defined by the EMS providers on scene.
[b] Any event where the number casualties and/or the severity of injuries exceed the ability of EMS personnel to provide optimal initial care all casualties.

Mass Casualty and Disasters

In the military environment, use of tourniquets during a mass casualty event is well established and adaptation of this use to civilian disaster care is natural.

Figure 1 shows an algorithm advocating that responders stop potentially massive bleeding first: this is easily and safely accomplished with a tourniquet. The prompt arrest of major extremity hemorrhage minimizes blood loss while allowing the triage provider to move rapidly to assess other patients. With multiple casualties, there may not be the time or manpower to apply an adequate pressure dressing.

After completing triage and other emergent procedures such as airway stabilization, medics would then be free to reassess the need for the tourniquet in patients on whom it was previously applied. Allowing providers to reassess wounds for ongoing tourniquet need under calmer circumstances maximizes the safety and effectiveness of this tool. Tourniquet reassessment and removal algorithms are presented below.

Finally, in order to minimize tourniquet times, we recommend that no patient with a tourniquet in place should have a triage code less acute then "yellow" and

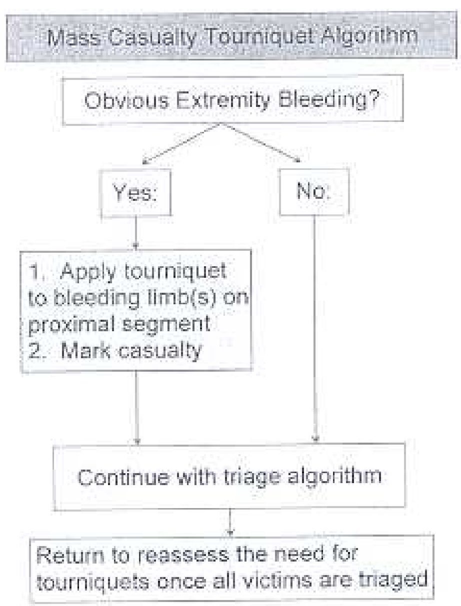

FIGURE 1. Proposed algorithm for mass casualty tourniquet use. Triage teams should apply tourniquets to patients with bleeding extremity wound(s) and continue with START or similar triage protocols. They also mark or label the casualty to alert others to the tourniquet.

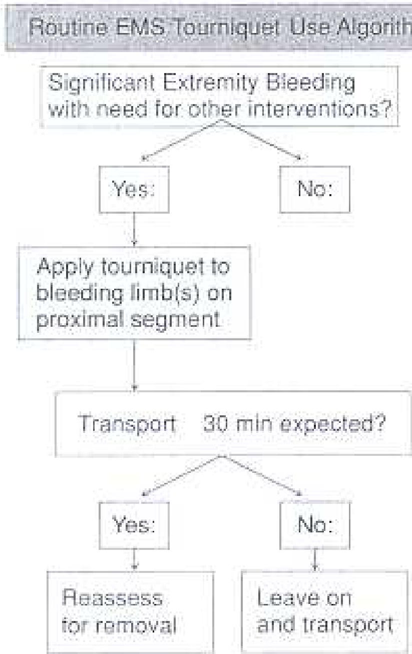

FIGURE 2. Proposed algorithm for routine EMS tourniquet use. Bleeding in patients with indications listed in Table 2 is arrested by a tourniquet placed primarily. If time, clinical situation, and personnel allow, a pressure dressing could be tried first.

that they have priority for transport. The presence of the tourniquet and the time that the tourniquet was applied should be prominently marked on each patient.

Routine EMS Use and Law Enforcement Considerations

Typical protocols for tourniquet application in EMS stringently limit the use of this device. In most simple single-patient extremity hemorrhage encounters, a tourniquet will not be required; standard pressure dressings will suffice. However, in cases of amputation, severe hemorrhage, multiple patients, or single patients with extremity hemorrhage combined with airway or breathing emergencies, a tourniquet must be available and providers must be well trained in its use. Figure 2 shows a proposed algorithm for safe and rational routine tourniquet use within a civilian EMS systems.

EMS providers are charged with providing sophisticated care in their daily jobs: airway interventions, vascular access, medication administration, defibrillation, and the like. Expecting them to be able to decide whether or not to apply a tourniquet is certainly within their scope of training and practice. Allowing them to reassess and remove tourniquets and monitor for further bleeding is also simply a matter of common sense, involving only simple protocols and training.

Control of bleeding is especially important in patients with multisystem trauma who need multiple interventions and immediate transport. Rapid control of extremity bleeding with a tourniquet facilitates other interventions and allows rapid transport to definitive care while minimizing blood loss. In multiply injured patients, we suggest allowing providers to place a tourniquet *first* to stop blood loss immediately, then attend to airway, breathing, or other emergent priorities following the military's "MARCH" protocol. After these are addressed, the medic may then return to see if the tourniquet is still needed. In cases with short transport times, well within the known safety margins of tourniquet time, rapid transport without removal is indicated. When delayed or prolonged transport is anticipated, efforts to replace the tourniquet with a pressure dressing should be undertaken.

We also suggest that law enforcement officers, especially those in high-risk operational settings, be allowed to carry tourniquets and given training on how to use them on themselves, their teammates, and other victims, in an effort to stop severe extremity hemorrhage while awaiting EMS arrival.

Reassessment and Removal of Tourniquets

Previous discussions of prehospital tourniquets have typically recommended leaving tourniquets on until removal by a physician, regardless of the time involved, while some systems have advocated loosening tourniquets intermittently for brief reperfusion intervals in the event of prolonged transport. We reject both of these approaches. Based on available evidence, safe reassessment of tourniquet need and tourniquet removal in the field can be accomplished with simple, standardized protocols and training. Figures 3 and 4 show proposed algorithms for reassessing the need for and performing the removal of tourniquets, respectively.

Future Directions

Improved Tourniquet Design

Multiple design features to improve safety and effectiveness could be incorporated into tourniquets for use in prehospital and disaster situations. For example, curved tourniquets, which fit the natural conical taper of an extremity better than do straight rectangular tourniquets, provide hemostasis at lower pressures and seem to allow longer tourniquet times.[20]

Padding under a tourniquet with two-layer dressings, like stockinette or cast padding, reduces the skin damage these instruments can cause.[81] It may be possible to incorporate more padding into nonpneumatic tourniquet models and thus reduce the risk of skin injury. Other simple, potentially effective design changes would include widening the nylon strap on which most new models are based and coloring them brightly to make them conspicuous.

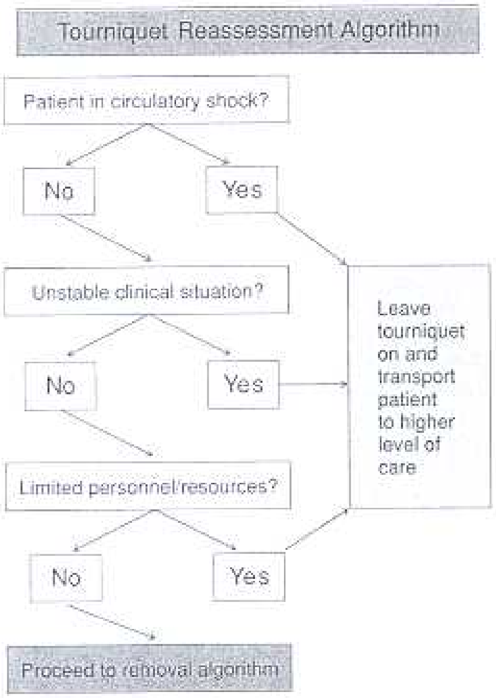

FIGURE 3. Steps to be followed to determine ongoing tourniquet need. The tourniquet should not be removed if the situation is unstable or there are not personnel or supplies available to place an adequate pressure dressing and monitor the site for rebleeding.

Finally, microelectronics could be incorporated to maximize both the effectiveness and the safety of tourniquets. Such "smart" tourniquets might detect flow through arteries beneath them and continuously self-adjust tension as the victim's blood pressure rises or falls, only applying the minimum pressure required to stop arterial flow. Other safety features, such as timers (allowing receiving facilities to know the tourniquet time) and alarms (to alert them to the tourniquet's presence), might also be added.

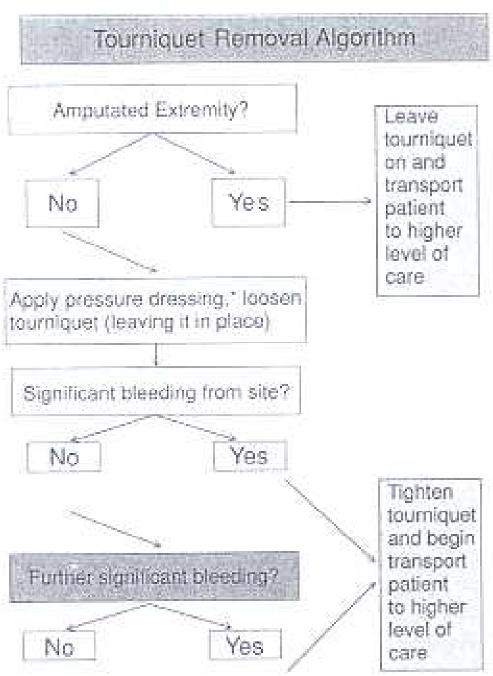

FIGURE 4. Algorithm for field tourniquet removal. A pressure dressing should be applied (*with a topical hemostatic agent if allowed and available.) The tourniquet is loosened but left on and the wound monitored. If rebleeding occurs, tighten the tourniquet to arrest bleeding.

Tissue Protection

Ischemia and reperfusion injury (IRI) is a known complication of prolonged tourniquet use and liberation of free radicals and other compounds after tourniquet release.

Recent work with n-acetylcysteine and preconditioning has not yet yielded success,[82] but as our understanding of this process improves, it is foreseeable that prehospital personnel will have access to compounds or techniques that may reduce IRI and further improve the outcome of tourniqueted limbs.

Research and Registry

Review of current and future uses of tourniquets is needed to continually improve our tourniquet protocols. Tumor boards, wound and trauma registries, and other prospective cohorts have enhanced medical knowledge about a number of conditions. Similar registries of tourniquet use should be encouraged and would be especially easy to initiate using data from recent military experience. This will help refine protocols, enhancing future safe tourniquet use. Controlled trials of prehospital tourniquet use are unlikely to be feasible given ethical and other clinical considerations. Appendix 1 presents a proposed data-collection form for use in a tourniquet registry.

Pediatrics

There is no reported prehospital experience with use of tourniquets for hemorrhage control in children. As previously noted, pediatric victims of violence often have the same injury patterns as adults; hence, they may also benefit from rapid extremity hemorrhage control with tourniquets. Further research to evaluate special considerations such as tourniquet size, childhood physiology, and other pediatric-specific issues must be performed in order to ensure maximum safety and benefit for all age groups.

Training

Continued safe and effective tourniquet use in the prehospital arena will be fostered by adequate training of personnel in use of this instrument. Appendix 2 presents a suggested outline of a tourniquet use training curriculum.

CONCLUSION

Traditionally, the risk-benefit calculus involved in the EMS use of tourniquets has been encapsulated in the phrase "lose a limb and save a life,"[5] because these devices have the potential to cause ischemic damage to a limb even when applied to stop life-threatening hemorrhage. Some authors, concerned with inappropriate use of tourniquets as well as reperfusion injury despite appropriate use, recommend prohibition. They state that there is no "exclusively clinical" reason to apply tourniquets, which should not be used except in the exigent circumstances of military or disaster situations.[83]

In contrast, Lee, et al. have suggested that there are "rare" circumstances when tourniquet use may indicated.[40] However, recent military experience with widespread tourniquet use by individual soldiers, front-line medics, and combat hospital personnel, combined with almost universal acceptance of tourniquet use in bloodless extremity surgery, indicates that the maxim of "tourniquet as last resort" in civilian EMS care is clearly antiquated. Instead, there should be a prominent role for these potentially life-saving devices in civilian prehospital care. EMS providers must be trained and comfortable with tourniquet use when extremity bleeding is a threat and standard methods like direct pressure and elevation are ineffective or impractical.

Penetrating extremity trauma is an increasingly common occurrence in our communities, whether associated with accidental injuries, firearm violence, or terrorist-related incidents. Experience and research indicate that life-threatening hemorrhage can be quickly and reliably arrested by the use of a simple tourniquet. This device allows limited numbers of providers to rapidly triage and provide hemostasis to multiple patients. Tourniquets can be self-applied by injured police, fire, or rescue personnel, allowing them to continue duty, if necessary, until safe evacuation and treatment are available.

Ischemic complications can be avoided by rational, protocol-driven use involving quick initial placement and rapid transport to definitive care, keeping tourniquet times to a minimum. When conditions allow, a tourniquet can be reassessed and replaced with a pressure dressing.

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APPENDIX 1. DATA COLLECTION FORM FOR TOURNIQUET REGISTRY

Tourniquet Registry Data Collection Form

Date of Encounter: ____________________

Time of Dispatch: (use 24-hour clock for times) ________ Time of Arrival at Hospital: ____________

Patient Identifier: (Run #, SSN, Med record, etc.) ____________________

Patient Sex: M F (circle one) Patient Age ____________ years old

Crew Members/Personnel: ____________________

____

____

Number of Victims on Scene: __________ Mechanism: Blunt Penetrating

Site of Tourniquet Application: (circle; use additional sheets for > 1 tourniquet applied to single victim)

Arm Leg R L

Tourniquet Applied by: Victim Bystander EMS Other: ____________

Measures Used Prior to Tourniquet Use: (circle all that apply)

Direct Pressure Pressure Dressing Pressure Point(s) Hemostatic Agent

Time of Tourniquet Application: ____________ Time of Tourniquet Removal: ________

Tourniquet Removed by: (circle one) EMS (name ____________________) Hospital Personnel

Total Tourniquet Time: (minutes) ________ Transport Time: (minutes) ________

Protocol Utilized for Tourniquet Placement: (circle one)

Mass Casualty/Disaster TEMS/Law Enforcement Routine EMS

Removal In Field/En Route: (circle one)

Attempted/Successful Attempted/Failed Deferred

Did Patient Require Pain Medications because of Tourniquet Pain? Yes No Unknown

Tourniquet-Related Complications (defined by higher level-of-care/Medical Control) (circle all that apply)

None Ischemic Damage VTE Compartment Syndrome Reperfusion Injury

Other: (explain)____________________

Type(s) of Bleeding Distal to Tourniquet: (as defined by higher level-of-care/Medical Control) (circle all that apply)

Capillary Venous Arterial

Appendix 2. Suggested outline of a tourniquet-use training curriculum.

Tourniquet Training Curriculum Items:

I. Background
History of the Tourniquet Controversy

II. Review of Hemorrhage Control
- Significance of Hemorrhage
- Hemorrhage Control Methods and Alternatives
- New trends: Military Use, Hemostatic Agents, etc.

III. Protocols for Tourniquet Use
- Application
  - Indications
    - Mass Casualty/Disaster Situations
    - TEMS/Law Enforcement
    - Routine EMS
  - Techniques
- Monitoring Effectiveness
- Removal
  - Indications
  - Techniques

IV. Quality Improvement/Registry Instrument

V. Practicum
- Scenarios for Practice Using Protocols
- Simulations to Practice Applying Tourniquet
  - Self
  - Partners
  - Active Hemorrhage Simulators*

* from Mabry RL. Use of a hemorrhage simulator to train military medics. Mil Med. 2005 170(11):921–925.