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TACTICAL COMBAT CASUALTY CARE: TRANSITIONING BATTLEFIELD LESSONS LEARNED TO OTHER AUSTERE ENVIRONMENTS

Bleeding Control With Limb Tourniquet Use in the Wilderness Setting: Review of Science

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The purpose of this review is to summarize tourniquet science for possible translation to wilderness settings. Much combat casualty data has been studied since 2005, and use of tourniquets in the military has changed from a last resort to first aid. The US Government has made use of tourniquets a health policy aimed to improve public access to bleeding control items. International authorities believe that education in first aid should be universal, as all can and should learn first aid. The safety record of tourniquet use is mixed, but users are reliably safe if trained well. Well-designed tourniquets can reliably attain bleeding control, may mitigate risk of shock progression, and may improve survival rates, but conclusive proof of a survival benefit remains unclear in civilian settings. Even a war setting has a bias toward survivorship by sampling mostly survivors in hospitals. Improvised tourniquets are less reliable than well-designed tourniquets but may be better than none. The tourniquet model used most often in 2016 by the US military is the Combat Application Tourniquet (C-A-T), and civilians use an array of various models, including C-A-T. Evidence on tourniquet use to date indicates that most uses are safe and effective in civilian settings. Future directions for study relevant to the wilderness setting include consideration of research priorities, study of the burdens of injury or capability gaps in caregiving for various wilderness settings, determination of the skill needs of outdoor enthusiasts and wilderness caregivers, and survey of wilderness medicine stewards regarding bleeding control.

Keywords: resuscitation, hemorrhage/prevention and control/shock, tourniquet/medical device/removal, emergency medical services, injuries and wounds/penetrating trauma, first aid, austere/out-of-hospital/prehospital

Introduction

Recent experiences of US military services have included a historically high survival rate of war casualties. One reason for this high survival is early, effective caregiving at the point of injury.[1,2] One improvement in military first aid has been the widespread use of tourniquets to stop bleeding from limb wounds.[3–6] As a consequence of this survival improvement, the administration of President Obama changed US public health policy in 2015 to improve public access to tourniquets.[7]

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Although international authorities consider recent developments within the science of bleeding control with tourniquet use to be weak evidence, such authorities state that tourniquet use is a recommended first aid intervention.[8,9] Furthermore, such authorities state that they believe education in first aid should be universal. Everyone, including the lay public and nonmedical military personnel, can and should learn first aid, which can include tourniquet use.[8,9] A scientific review of tourniquet use to control life-threatening bleeding is now timely to aid in potential application to specific aspects of civilian care. The purpose of the present review is to summarize tourniquet science for possible translation to wilderness settings.

Burden of Injury that Indicates Tourniquet Use

Penetrating trauma is common, disabling, and potentially lethal in settings like battlefields and cities, but it is less

common yet more challenging in rural and wilderness settings.[4,10,11] Although combat evidence has advanced the state of first aid science in mechanical control of prehospital bleeding, many of those findings were gained in urban centers like Baghdad, Iraq, in 2006 when time from injury to hospital was similar to that of civilian care.[4,12,13] In Baghdad, the duration of tourniquet use was brief (91% were $\leq$2 hours).[4] Exsanguination deaths from limb-wounded civilians have occurred but are not well evidenced, and some authors have considered them potentially preventable by early tourniquet use.[3,14–23] New surveys of the burden of injury in wilderness settings, including limb wounds in need of bleeding control, could help develop best caregiving practices. This knowledge gap may be considered to become a research priority.

Safety of Tourniquet Use

Opinions on tourniquet safety are mixed in surveys of war casualties because older reports, often from authors caring for civilians, indicated that care led to unacceptable rates of morbidity.[24–28] Recent military surveys have reported minor morbidity because most complications were infrequent, temporary, and incomplete.[4,29]

The US military took a different approach by training all servicepersons in tourniquet use and supplying tourniquets to them.[30–33] Limb ischemia from tourniquet use is important because skeletal muscle, the main tissue of the limbs, is the tissue type most sensitive to ischemic duration. Muscle ischemia can cause muscle cell damage, myonecrosis, myoglobinemia, kidney failure, limb loss by surgical amputation, and death.[4,29] Morbidity of tourniquet patients is sometimes evidenced as higher than expected.[34–37] In morbidity−mortality analyses, only survivors have morbidity, so higher morbidity rates may be expected if there was lifesaving benefit to tourniquet use.

A policy of last resort often meant that the intervention was done too late to be lifesaving, and bleeding control with tourniquet use eventually became first aid, as recommended by international authorities.[8,9] However, either the treatment effect size of tourniquets, such as the percent survival with or without tourniquet use, appears to be small or a survival bias exists in the way we gather data.[38,39] Altogether, such findings indicate that tourniquet science needs more research to clarify risks and benefits.[38,39]

Effectiveness of Tourniquet Use

The effectiveness of tourniquets can be assessed mechanically, physiologically, and situationally. Efficacy of bleeding control in the laboratory setting as a yes−no outcome, such as in a bleeding manikin, has merit in differentiating performance of tourniquet models, users of tourniquets, and techniques of use. Such knowledge can help inform selection of the best devices, assess the performance of students or instructors, and develop best tourniquet practices.[40–42] In care research, due to a survivor bias, hemorrhage control is rarely associated with improved casualty outcomes, but one study did associate bleeding control and improved survival.[43] Moving along the causal chain from bleeding to its control and on to shock control, rarely is tourniquet use associated with the latter,[44] and such absence of association is likely due to survivor bias. One research study of casualty data from a war trauma registry did show a shock control finding.[44]

Best care seeks to be safe, effective, and fast, and for tourniquet use, absence of any one of these elements may be lethal.[1,4,5,29,43] A small but growing body of science on training tourniquet users indicates that quality of training appears important to user performance.[32,45,46] For example, Wall et al reported a survey of tourniquet knowledge among civilian prehospital providers, and many did not know information important for optimal tourniquet use.[47] Poor knowledge was found in all groups irrespective of certification and experience. Most (91%) did not know that wider tourniquets require less pressure for arterial occlusion, and most (69%) did not know that stopping venous flow without arterial control is harmful.[47] Useful metrics of user performance include time to stop bleeding, blood volume lost, pressure under the tourniquet, ease of use, and safety data like mishaps, device breakage, and user injury. Much of this type of information is difficult to obtain from a care setting, but the caregiving records in the military today are better than before for details of bleeding control status, device identification, intervention effects, and the time progression of casualty status.

Through sustained and comprehensive efforts to improve such recording, the military came to understand better tourniquet performance and thereby improve user performance. The science of tourniquet user development is in need of data to improve awareness of the need to focus on the performance of people and not only on the performance of tourniquets. Training users to be effective may take a couple of tries, but training them to be simultaneously effective, safe, and fast may take more repetitions of use to gain the desired skill level. Such training of users to a higher level of performance likely takes more resources like time of both instruction and practice.

Tourniquet use was recommended in an evidenced-based guideline published in 2014 by Bulger et al from

the Committee on Trauma of the American College of Surgeons; for "the overall quality of the evidence for survival benefits of tourniquet use was upgraded from Low to Moderate, based on the large effect size."[48] However, the sources of the effect size upon which the upgrade was made do not evidence a treatment effect size because they evidence a shock effect size.[1,5] The sources used were observations of survival based on whether shock was present at the time of first tourniquet use, and this method cannot establish a valid treatment effect size.[1,5] Treatment effect size is determined with methods other than those used in the sources cited, and when appropriate methods were used later in one study, the treatment effect size was found to be zero.[38,39] Another study that later investigated treatment effect size reported a preliminary finding of a shock control effect with improved survival among casualties with severe injury and massive transfusion.[44] Such casualties had a larger treatment effect size, whereas other casualties had worse outcomes.[44] Currently, that preliminary report awaits further data to investigate the treatment effect size more fully.

The Hartford consensus, a group of experts, has offered guidelines regarding bleeding control in civilian settings.[49] The authors surmised that "immediate responders should attempt to stop or slow massive hemorrhaging initially by using their hands (gloved whenever possible) to initiate primary compression. This compression should be applied directly or just proximal to the site of hemorrhage and with the use of sustained, direct pressure. Performing this task may be difficult for someone without any first aid training, but it will significantly enhance the survival of the actively hemorrhaging injured victim. Once the professional responder arrives at the scene, care should be transferred to this individual because he or she will be equipped with and trained in the use of more sophisticated hemorrhage control methods, such as hemostatic dressings and tourniquets." This is prudent advice, but future datasets may help to decide the relative merits of the items discussed.

Regarding the effectiveness of improvised designs of tourniquets in first aid, a small but growing body of science indicates that these designs are inferior to well-designed tourniquets, but there is only limited evidence to indicate that improvised tourniquets are better than none at all.[4,50–52]

In a 1996 report of a 2-year survey of military caregivers in special operations medicine, Butler et al took an established deduction that tourniquets may control bleeding and potentially save lives and made a strong and novel development by applying it directly to situations like Care Under Fire as phases in tactical combat casualty care.[53] However, few people in the military took heed of this idea until 2005.[31]

Best Practices in Tourniquet Use and its Adjuncts in Bleeding Control

The tourniquet model used most often by the US military in 2016 is the Combat Application Tourniquet (C-A-T), a strap-and-windlass design now in its seventh version, called Generation 7. The C-A-T is easy to use, small, light, and relatively inexpensive, and it has a large body of science. The C-A-T was shown in one study in care to be the most effective field tourniquet of the nonpneumatic design, whereas the overall most effective field tourniquet was the Emergency Medical Tourniquet (EMT), a pneumatic tourniquet.[4] The C-A-T has been recommended to be issued as part of the first aid kit of individual soldiers when deploying to war.[31] The EMT has been recommended for issue to military medics; although the recommendation has not been enacted, it is occasionally reconsidered.[31]

These 2 tourniquet models are the leading candidates in 2016 for recommendation for individual use and placement in some medical kits. The evidence to date generally favors the C-A-T to be carried by individuals, whereas the EMT may be carried in vehicles, kept in clinics and emergency departments, or carried in medical packs larger than an individual's first aid kit. Other authors, however, provide further opinions with guidance for consideration.[54] For example, the Committee on Tactical Combat Casualty Care (CoTCCC) recommends C-A-T, EMT, and a Special Operations Forces Tactical Tourniquet.[54] The decisions and implementation of such guidance currently is left to individuals and organizations, and currently the wilderness community has not reached a consensus and has not reported much on its current practices.

Regarding civilian experience with tourniquet use, several reviews and reports have been made, especially since 2014. A number of reviews recommend civilian use of limb tourniquets in emergencies.[55–60] The number of cases reported is usually fewer than in military reports.[61] Reports of cases with tourniquet use infer potential lifesaving benefits for injured civilians and law enforcement officers,[61–78] but implementation of use is uneven.[70] Studies show the ability of user to perform well enough,[71] reported that users felt tourniquets were an intervention likely to save a life but were also likely to possibly cause harm if used inappropriately,[72] and confirmed that users reliably attained bleeding control.[70–78] Tourniquet evidence to date indicates that most uses are safe and effective in civilian settings, as they are in military settings (Table).[62–78] However, to date, most reports are

Table. Key points of tourniquet science with level of evidence

Key point of tourniquet science	*Level of evidence*	*References*
Survival benefit (yes−no, %, duration)	Weak	1,5,43,66,77,78
Survival benefit in a wilderness setting	Evidence is absent	None
Safety (risk of morbidity or injury from care)	Weak	4,24,30,43,62,65,69,71,73,75,76,78,89
Safety in a wilderness setting	Evidence is absent	None
Bleeding control (yes−no)	Weak	4,5,32,45
User skill acquisition	Weak	23,41,42,45,46
Patient outcome in short term	Weak	4,5,22,24,30
Patient outcome in long term	Evidence is absent	None

limited to first-world countries like the United States, Canada, and Israel.

Regarding pressure dressings as an adjunct to tourniquet use, a small but growing body of science is accumulating and generally confirms the utility of such dressings and wraps[79–83]; however, the science is weak because few reports address a first aid context and few make comparisons of performance among available techniques.

For conversion from tourniquet use to another means of bleeding control, such as a pressure dressing or wound packing with overwrapping of the limb, a small but growing body of science is refining guidelines for such changes[24,84,85]; however, there is little empiric evidence upon which to develop best practices. Particularly relevant is the shortened duration of limb ischemia distal to the tourniquet because the red meat part of the skeletal muscle is the tissue of the limb that is most sensitive to ischemic duration. However, the science of ischemic duration is complex and not fully explored. As an example, the temperature of the ischemic tissue affects its risk of complications due to ischemic duration because coolness lessens the oxidative demands of the tissue. Furthermore, tourniquet ischemia is of a greater amount than that with wraps and packing because with the latter two only local tissue, and not the entire distal limb, is ischemic. Emergency tourniquet use can allow for brief control of bleeding and make early conversion to another means of control easier because the rate of bleeding during the application is stopped or slowed to allow for better wound and patient assessment.

According to multiple senior military medics with extensive clinical experience, first or very early use of tourniquets can allow for easier, more organized, and more reliably effective aftercare such as wound packing because wound assessment is not as rushed, incomplete, obscured, or challenging as when done during a crisis such as major exsanguination. These general experiences are integrated into the Tactical Combat Casualty Care Guidelines to include permission for first use of tourniquets in Tactical Field Care.

Such first use of tourniquets is not restricted to only Care Under Fire. The science of conversion from tourniquets to other means is suitable for research and development because there are many evidentiary gaps that may be filled in manikin or volunteer studies. Furthermore, such conversion is a current research priority of stewards like CoTCCC. However, few manikin models for testing are adequately developed for the purpose of assessing conversion for the topics of interest among users because few manikins can measure blood loss, pressure, and time while allowing suitable assessment of effectiveness of tourniquets, packing, and wrapping. The simulation community may be able to develop suitable manikins in the future. If these become available, the ability of investigators to gather empiric data can then allow for faster development of best practices than is possible presently without such test apparatuses.

Tourniquet use in prolonged field care has recently become a hot topic in the military because dispersed servicepersons operate with limited resources like medical equipment, transportation, and communication, but little is known about the science of such care as few data are available for analysis. There are few knowns, many unknowns, and no clear best practices or techniques, but guidelines are being formed and research topics abound.[86–89] Drew et al have published a guideline for prolonged field care in the military, and this is a suitable referent for civilian consideration as it describes a procedure for qualified and trained medical personnel to safely exchange limb tourniquets for local wound dressings—a process called conversion.[85] A case report and review of prolonged use of tourniquets in a war setting noted the importance of limb temperature because the duration of tolerable ischemia is greater if the limb is cool.[89]

Prolonged environmental exposure risks mechanical degradation of the material properties of field tourniquets, so it is recommended that they be protected from the elements by being stowed in a first aid pouch or case.[90,91] A rule of thumb is to treat a tourniquet like a lifesaving medical device and not to wear it exposed to the sun and elements like a pedometer.

Some authors recommend tourniquet use to prevent reperfusion injury and mitigate risk of crush syndrome after a limb is crushed, but limited experience has been reported to date.[92,93]

Future Directions and Summary

Future directions include consideration of research priorities. Candidates for such priorities include epidemiologic-like study of the burdens of injury or capability gaps in caregiving for various wilderness settings and determination of the skill needs of outdoor enthusiasts and wilderness caregivers. A particular low-hanging fruit includes a survey of knowledge among wilderness medicine stewards regarding bleeding and its control.

In summary, the present review described the knowns and unknowns of tourniquet science for bleeding control in the wilderness setting. Although the combat casualty care experience of the military services has generated much data and knowledge during recent wars, few of these findings pertain directly to the wilderness setting; in particular, prolonged prehospital ischemic time remains an uncommon clinical challenge. Altogether, the military experience indicates that the scientific work can be done, but effort and perseverance are needed to move current care toward best care. Such an experience has turned tourniquets from a means of last resort to a means of first aid, and such an experience can be a reference for the wilderness community to chart a course on its journey to translating military lessons to the civilian sector.

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