Warning

Tourniquets Risk Frostbite in Cold Weather

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ABSTRACT

We sought to better understand the frostbite risk during first-aid tourniquet use by reviewing information relevant to an association between tourniquet use and frostbite. However, there is little information concerning this subject, which may be of increasing importance because future conflicts against near-peer competitors may involve extreme cold weather environments. Historically, clinical frostbite cases with tourniquet use occurred in low frequency but in high severity when leading to limb amputation. The physiologic response of vasoconstriction to cold exposure leads to limb cooling and causes a reduction of limb blood flow, but cold-induced vasodilation ensues as periodic fluctuations that increase blood flow to hands and feet. In animal experiments, tourniquet use increased the development of frostbite. Evidence from human experiments also supports an association between tourniquet use and frostbite. Clinical guidance for caregiving to casualties at risk for frostbite with tourniquet use had previously been provided but slowly and progressively dropped out of documents. **Conclusions:** The cause of frostbite was deduced to be a sufficiently negative heat-transfer trend in local tissues, which tourniquet use may worsen because of decreasing tissue perfusion. An association between tourniquet use and frostbite exists but not as cause and effect. Tourniquet use increased the risk of the cold causing frostbite by allowing faster cooling of a limb because of reduced blood flow and lack of cold-induced vasodilation. Care providers above the level of the lay public are warned that first-aid tourniquet use in low-temperature (<0°C [<32°F]) environmental conditions risks frostbite.

KEYWORDS: *bleeding control and prevention; first aid; prehospital care; freezing cold injury; complication; wounds and injuries*

Introduction

In common emergencies[1–3] when a need arises to stop limb-wound bleeding,[4–7] tourniquet use has lifesaving benefits.[1,8,9] When blood flow to a limb is stopped, convective heat flow is also stopped.[10–12] Loss of such a heat input carried by blood permits the limb tissue to cool toward a lower ambient temperature or warm toward a higher one, depending on the environmental circumstances.[13–15] Frostbite can only occur when the environmental temperature is <0°C (<32°F).[16]

Climate change trends in global warming may lead one to think that military services will be operating in warmer environments. That is true globally on average, but it also suggests a paradoxical consequence: Warm trends risk cold conflicts. For example, warming has resulted in the melting of arctic ice.[17] With receding sea ice, competition for natural resources in arctic areas is likely to increase, such as for previously inaccessible oil reserves where national boundaries remain disputed. Sea lanes across the Arctic Ocean are opening, and their use can cut ocean transit times and distances while avoiding fees at the Panama and Suez Canals, but these sea lanes are largely in Russian waters, and the Russian government has become increasingly hostile.[18,19] These facts increase the likelihood that US forces will be deployed to colder areas of the world for peacekeeping, disasters response, and other national security operations. Given developments in the US arctic strategy,[19,20] cold-weather training operations may increase, especially with allies and partners. Medical personnel planning for cold-weather operations should emphasize prevention of cold injury, prepare to care for traumatic injuries in cold weather, and plan to treat individual casualties with both a cold injury and a traumatic injury.

Most tourniquet uses have not occurred in extreme cold weather, an operational environment to which militaries have recently returned their attention.[19,21–23] While most of the recent conflicts involving the US Military have occurred in warm environments, future conflicts against near-peer competitors might occur more frequently in extreme cold weather environments, making considerations of possible side-effects of tourniquet use timely. In military operations conducted in extreme cold weather, frostbite can be common,[24–26] disabling,[27–31] costly,[28,32,33] and, if inappropriately managed, potentially lethal.[35–39] Tourniquet use in war has been reported to be associated with subsequent frostbite injury among many cases that had limb loss by surgical amputation.[39–41]

We sought to better understand the frostbite risk during first-aid tourniquet use by reviewing information relevant to this association. We use the term "tourniquet-hastened" frostbite

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to indicate that tourniquet use does not cause frostbite but that it can quicken the development of frostbite and increase its incidence. This is not a systematic review of science: To the first-aid community, it is a warning.

Tourniquet-Hastened Frostbite Cases Occur in Low Frequency but are High Severity

Frostbite cases with tourniquet use were reported in both World Wars by an Austrian surgeon, Lorenz Böhler, who specifically recognized that tourniquet use risked frostbite and later limb loss.[39] He noted little in his orthopedic textbook about first-aid tourniquets in the cold:

> When a limb is constricted, the nourishment obtained through the blood stream is shut off, and if the constriction is maintained for several hours, the extremity must die. This danger is greater in wintertime. In both World Wars, I saw many limbs needlessly constricted, which were frozen during transport because of the use of a tourniquet, and which had to be amputated.[39]

Likewise, at the Battle of the Bulge in World War II, a Soldier reported himself as a tourniquet-hastened frostbite case.[42] In a large sample of 1,450 battle casualty deaths of US Service Members in World War II studied, only eight had frostbite or other cold injury as a contributory or associated condition identified at autopsy.[43] Among these deaths, a small proportion, 1% (8/1,450), had a nonbattle cold injury and a battle wound—for example, a casualty having combined injury mechanisms: frostbite and gunshot wound. In a Korean War sample of US combat casualties surviving to military hospital admission in Japan, very few (1%) battle-wounded casualties had an associated cold injury, but this accounting was made at a US military hospital in Japan on a ward of principally frostbite cases.[44] Those more seriously wounded in Korea were segregated to other wards and hospitals and lost to frostbite accounting, despite some potentially having been frostbitten. Thus, the author of this study[44] noted a likely undercounting of associated war wounds among the frostbite cases and also did not note tourniquet use.[25,44] In Korea, two nonfiction historical books specifically note combined injury mechanisms of cold injury with battle wound in individual casualties, but no tourniquet use was noted.[45,46] In Korea, there were two documented tourniquet-hastened frostbite cases, each reported by the casualty himself.[47–49]

A report of a 1962 airplane crash had a case of tourniquet use in which the Soldier froze to death, but there was too little detail provided to posit a potential association.[50] In our search of these early cases, we found no case reported of a person who froze to death while a limb tourniquet remained applied. Perhaps to observers present at the death, tourniquet use may have become unimportant to the situation at hand.

In recent combat operations, tourniquet use has been common[1–3] while frostbite has not.[51] A 2010 study reported 19 cases of cold-weather injury identified in the Afghanistan conflict; only two of these included frostbite; no mention was made of tourniquet use.[51] In 2022, we asked the Department of Defense Joint Trauma System (https://jts.health.mil/) for a preliminary count of registrant cases of either limb frostbite or tourniquet use, and 14 frostbite cases and 7,510 tourniquet cases were documented from 2002–2021. Among cases, none had both conditions recorded.

There were very few reports found of cases with an association between tourniquet use and frostbite. Only Böhler's textbook had "many cases."[39] The clinical cases found primarily occurred in large-scale combat operations. Because wounding and frostbite totaled 1% in two different war samples,[43,44] we deduced that 1% is a rough guess of a maximum rate of potential tourniquet-hastened frostbite cases. Tourniquet-hastened frostbite cases occurred at low frequency, while many had high severity because limbs were amputated. The information indicated that tourniquet-hastened frostbite cases can exist, but detection, recording, and reporting has been limited, in part because of difficulties of documentation during war or limited awareness of the potential association between tourniquet use and cold injury.

Clinical Tourniquet Uses to Cool Limbs in Amputation Surgery

Tourniquets have been used in surgical studies of hospitalized patients with severely diseased limbs to reduce risks associated with anesthesia or the amputation itself.[52,53] This method of amputation includes isolating a limb with tourniquets, followed by freezing with ice, and then surgery.[54] The cessation of blood flow was an important factor in determining how thoroughly[55,56] and how fast a limb was chilled.[55] A report advised caregivers to protect the other limb from iatrogenic cold and warned that limbs and icing should be carefully monitored by nursing and medical personnel.[54] These recommendations imply that thermal management of diseased limbs requires skill and vigilance to minimize complications and that achieving optimal care entails a caregiving workload to improve awareness, train personnel, assess patients, monitor treatments, and troubleshoot problems. Altogether, these surgery reports indicate that tourniquets might reliably hasten and deepen the chilling of limbs by the speed and magnitude of cooling.

The Physiologic Response to Cold Exposure Leads to Limb Cooling

Investigators have studied[10,57–60] and reviewed[61–65] how cold exposure affects limbs. Important factors responsible for environmental cooling to result in frostbite include ambient air temperature, the rate of air movement, and duration of exposure.[66] Upon exposure of the body to cold, a series of physiologic responses occurs that is thought to reduce the risk of hypothermia in the body's core.[61,67] The initial mechanism of cold-induced vasoconstriction is a sympathetically mediated reflex.[65] Skin temperature of the fingers and toes was reported to rapidly and exponentially decrease over time to a level approaching that of the ambient environment.[64]

Vasoconstriction profoundly decreases blood flow. For example, when a human arm was immersed in cold water, a rapid fall of deep-muscle temperature resulted from the greatly decreased blood flow, which at a water temperature of 13°C to 20°C (55.4°F to 68°F) became sometimes almost imperceptible.[67] Vasoconstriction of blood vessels in the cold tissues had essentially stopped blood flow.[58,62,68]

The heat conductivity of the skin increased with depth from the skin surface and with the amount of blood flow for acral parts, such as fingertips.[15,69,70] Vasoconstriction during core hypothermia was reported as sufficiently strong to reduce heat flow to <0.1W,[64] meaning that flow effectively stops.

In 1946, investigators used a venous tourniquet effect of a plethysmograph to measure hand blood flow while a

calorimeter measured heat loss by radiation, convection, and evaporation.[71] Blood flow rates as low as 0.15mL/100mL of hand tissue were recorded after cold exposure of the body for several hours. The cold eventually reduced flow 100-fold,[71] an effect similar in size to arterial tourniquet use at warm temperatures.[72–74]

Büttner[14] measured temperature changes in the hand exposed to –26°C (–14.8°F) with and without a tourniquet to occlude blood flow, and results indicated that blood flow to the hand became practically zero when it was suddenly cold-exposed. The temperature of the back of the hand with circulating blood decreased practically as fast as did that of the hand without circulating blood (because of tourniquet use). Local convective heat flow in the blood had stopped when the cold had set in. The skin surface temperature had dropped in the same manner as does that of a corpse starting at the same initial temperature.[14]

Blood flow was a major source of limb heat, but when blood flow was decreased by vasoconstriction or tourniquet use, that blood's heat flow was interrupted.[12] The reduced blood flow to the limbs in response to cold exposure served to limit heat loss from the limbs, yet reduced blood flow simultaneously contributed to limb cooling.[12,61] Periodic cold-induced vasodilation is thought to be a way that the body attempts to rewarm its limbs; cold-induced vasodilation is addressed below.

Using a tourniquet effect, investigators experimentally compared the heat loss with free or arrested limb circulation to calculate the heat losses from blood flow.[58] For example, investigators compared results of the fingertip to the whole hand of a person and showed that the maximum fingertip heat loss rate surpassed that of the hand by more than 10-fold.[58] These heat loss findings quantified thermal effects of tourniquet use and showed that acral fingertips lose heat faster than hands, thus informing why acral tissues are at increased risk of cold injury. In other analyses that included tourniquet effects, an investigator identified a thermal intuition error concerning local limb flow, namely the hand, that "[t]he heat delivered by the circulating blood is proportional not to the rate of blood flow but to the product of the rate times temperature change as it circulates through the hand."[75] Thermal intuitions, a topic of study,[76] apply to limb cooling[75] and thus may affect caregiver control of limb wound bleeding.

Investigators studying contact cooling of the skin when in contact with cold objects found a difference in the shape of the contact cooling curve between occluded (zero) blood flow and unoccluded (close-to-maximal) flow.[12] Finger blood flow occlusion consistently showed Newtonian cooling, whereas the unoccluded skin had a non-Newtonian cooling behavior in 13 of 18 exposures, presumably the result of cold-induced vasodilation rewarming the skin. The lack of heat input because of blood flow occlusion further cooled the finger skin.[12]

Altogether, vasoconstriction and tourniquets act alike in that both can essentially stop blood flow. However, the volume of tissue differs because the tourniquet routinely affects more of the limb. If the tourniquet affects a larger volume of the limb compared with an initial frostbite lesion, a tourniquet may plausibly increase frostbite volume. Irrespective of frostbite or tourniquet occurring first, a risk of larger frostbite volume appears plausible. This deduction about volume aligns with Böhler's book[39] and indicates a plausibly greater severity of cold injury with tourniquet use.

Cold-Induced Vasodilation is a Periodic Increase in Blood Flow to Hands and Feet

Cold-induced vasodilation has been studied[58,66,77] and reviewed[64,78–80] but is still not fully understood. During cold exposure, initial peripheral vasoconstriction is often followed by a vasomotor response of spontaneous fluctuations of vasodilation in acral tissues (e.g., fingers, toes).[66,81] Despite exposure of a distal limb to extreme cold, experiments have demonstrated an ability to maintain a comfortable limb temperature as long as the rest of the body is maintained at a sufficiently warm temperature.[82] Investigators have found that, if cold-induced vasodilation occurred, local freezing did not take place because cold-induced vasodilation tempered the effects of vasoconstriction.[58] Other investigators[66,78] deduced that cold-induced vasodilation evidently acted to maintain a balance between core body heat preservation and local tissue perfusion. However, cold-induced vasodilation becomes essentially absent when the core becomes hypothermic.

Havenith et al[79] demonstrated that, after cold-induced vasodilation onset increased hand temperature, cold-induced vasodilation flow decreased, and then the hand cooled again. In another study, cold-induced vasodilation fluctuations produced blood flows that ranged from 7-fold to 10-fold (maximum/minimum).[83] During decreases of experimental cold-induced vasodilation blood flow, the graphed maximal steepness of the downward slopes in skin temperature were equal to those observed when blood flow was stopped in the limb by an inflatable cuff having a tourniquet effect on the forearm.[83] In a cold man, where cold-induced vasodilation blood flow has fallen and only the nutritive (capillary) flow supplied the tissues, this flow was so small because of vasoconstriction that it was unable to convey any heat to the hand.[84] A restriction of blood flow to the hand induced by a tourniquet made cold-induced vasodilation disappear.[14,69]

Altogether, evidence indicates that a tourniquet effect can mechanically block local cold-induced vasodilation and its subsequent rewarming of hands or feet. If a tourniquet impairs cold-induced vasodilation, then the onset of a local cold injury such as frostbite might plausibly be hastened. Cold-induced vasodilation occurs only in acral tissue, whereas a tourniquet can affect larger segments of a limb. Thus, tourniquet use may worsen frostbite by affecting a greater tissue volume than just that of the hand or foot.

Tourniquet Use and Frostbite: Experiments

In a 1947 experiment, no benefit was found in rabbits for tourniquet use to treat frostbite.[13] In animal experiments, an association between tourniquet use and frostbite development has been studied.[81,85–87] Investigators looking for vascular reactions associated with frostbite studied venous tourniquets applied before and after cold exposure and found that, in animals without cold exposure, venous tourniquets slightly decreased the local temperature of the limb.[86] The clinical risk of frostbite has been repeatedly reported for impaired circulation of the limbs by a tourniquet effect—both arterial and venous—but this study measured limb temperature reduction and so estimated the quantity of risk. A few experiments in cold conditions suggested that tourniquet effects or vascular clamping hastened the onset and worsened the severity of frostbite.[81,87,88]

Investigators have justified tourniquets to hasten frostbite to mimic frozen digits of patients wearing constricting boots or gloves at the time of cold injury.[87] The varied ways to obstruct limb circulation are clinically relevant because each risks faster and worse cooling rates of tissue under and distal to the sites of external compression.

In an animal experiment of deep frostbite in bone, researchers sought to decrease the variability in physiology resulting from known problems such as protective cold-induced vasodilation rewarming of the cooled limb and the supercooling phenomenon,[81] a process of cooling a liquid (e.g., extracellular fluid in the skin or soft tissue) below the freezing point without solidification. The time required to end supercooling was reliably shorter with a tourniquet than without, and blocking cold-induced vasodilation by tourniquet use seemed to hasten and more reliably worsen the severity of frostbite.[81] The investigators inferred increased severity because they controlled the cold-exposure times so that durations of frostbite were longer when its onset was earlier, leading to worse lesions. Supercooling has been noted as a normal phenomenon.[89,90]

Methods to investigate frostbite experimentally need to improve the reliability of onset, speed of onset, and controllability of severity of the induced frostbite, thereby allowing more rigorous standardization and comparison across studies. It is important to make experimental frostbite severity more uniform and to reduce risks associated with anesthetic use. Limited animal evidence indicates that tourniquet use worsens the development of frostbite. Altogether, such experimental frostbite in animals does not closely mimic clinical frostbite because frostbite in humans is often slower in onset, affected by clothing, and more varied in severity. However, limited experimental evidence derived from animals indicates that an association between tourniquet use and frostbite development exists, as Böhler[39] noted. Although the risk of tourniquet-hastened frostbite is rarely mentioned in first aid, the association is now more often described as a technique used in physiological experiments. Tellingly, we found no animal experiment intended to inform prevention and control of clinical tourniquet-hastened frostbite.

In a translated summarization of a Japanese human experiment,[91] a text section, entitled "Obstruction of Blood Circulation," noted:

> We have already noted that when the easily frozen extremities of the human body are cooled, the blood circulating in those parts supplies the heat required to counteract further cooling. Should this blood flow be obstructed in one way or another, the anti-cooling action is weakened or ceases, and continued loss of heat will lead to the onset of freeze injury. In this connection, one may recall that a wounded leg dressed with a tourniquet or a foot in an undersized shoe is easily frozen. The influence of a tourniquet in inducing freeze injury can be seen from Tables 25 and 26. Thus the use of a tourniquet doubles the speed of body heat loss. We obtained this result from experimentation with healthy persons. Needless to say, in the case of a wounded limb, the loss of heat is further accelerated by bleeding.[91]

The tourniquet halved the frostbite onset time, an experimental effect in a clinically relevant size. The wording appears as if the translator meant that the distal limb was a body part and did not mean that this heat loss was from the core. The time parameters tabularized appear to be in minutes and seconds; if so, the tourniquet-hastened time differences are of the order of 1 to 5 minutes at −34°C to −36°C (−29.2°F to −32.8°F) in a wind speed of 0.46 to 1.29m/sec.

Clinical Guidance for Caregiving to Casualties at Risk for Frostbite With Tourniquet Use

A US Army technical bulletin on cold injury estimates an onset time to cheek-skin frostbite ranging on the order of 5 to 30 minutes, depending on personnel susceptibility, severity of temperature, windspeed, and whether the skin is wet.[16] Beyond water, blood or sweat qualify as wetting. However, the bulletin does not mention tourniquets, although it mentions restrictive clothing, gloves, and facemasks, which can fit tightly and so restrict the blood flow to the fingers and face, increasing the susceptibility of these areas to frostbite; such restriction is analogous to a tourniquet effect on a limb. With the exception of contact frostbite, there is no risk of frostbite when the ambient air temperature is above 0°C (32°F). Contact of a casualty or tourniquet user to a cold metal component of a tourniquet, such as an aluminum rod used to tighten the band around the limb, may cause contact freezing promptly at the site where the bare skin and metal touch, but to our knowledge, this phenomenon has only been preliminarily studied in our laboratory in unreported work on poultry groceries.

Böhler noted cases of tourniquet use with frostbite and judged that tourniquets had been selected too often or used too long in such cases, but he did not comment on tourniquet removal in the field or at the hospital.[39] Conversion of tourniquets may not be clinically feasible if field caregivers identify frostbite distal to the tourniquet in a setting where they cannot ensure that the thawed frostbite will not later refreeze. In practice, this is a difficult decision relying on prediction. Böhler[39] noted that caregivers sometimes needlessly left the limb constricted by use of a tourniquet during transport, with the implication that tourniquet conversion to other means of bleeding control was possible. For a casualty with a tourniquet and a distal site of frostbite, the volume of tissue distal to the tourniquet and not already frozen is at higher risk to become frostbitten, thereby worsening the cold injury volume and likely losing more of the limb volume to complications requiring surgical amputation. Such a scenario complicates judging the clinical conundrum of whether to rewarm distal frostbite in the field.

Wolff and Adkins[92] advised that care be used to prevent frostbite in sub-freezing weather. Although they gave no example of such care, their advice implied that thermal management of injured limbs was useful to prevent frostbite. This intent is sound, but it presumes that a general reader knows what such care would entail. Few people with whom we have discussed this tourniquet-hastened frostbite risk point were aware of its risk or management, although they quickly grasped the risk as it was explained. Tourniquet hastened frostbite risk and thermal management of injured limbs remain awareness gaps in knowledge and capability.

In both World Wars and in the Korean War, clinical advice occasionally noted that in cold weather, tourniquet use makes a limb susceptible to freezing.[39,92–94] Two senior surgeons noted that, while care was taken to prevent frostbite and other cold injuries in cold and freezing weather, it was the rule to leave

uncovered an extremity about which a tourniquet had been applied and never to employ artificial means to warm it.[95] At the end of World War II, a US Army medical bulletin included guidance that a limb with a tourniquet applied should have its temperature lowered as much as feasible, short of actual freezing.[96] In 1950, a military report of an arctic exercise advised to "stop hemorrhage first: Tourniquet, pressure points, and bandage."[97] It then noted: "If tourniquet is applied, remember that heat is also shut off to [the] injured member [limb]. Freezing will result unless external heat is applied."[97] A military physician with field experience in combat noted in post-war instruction that, "During cold weather an extremity with a tourniquet applied is unusually susceptible to freezing and gangrene formation. During the freezing months the aidmen and surgeon should be unusually careful not to apply a tourniquet unless it is absolutely necessary and should do so only when repeated efforts to control hemorrhage have failed."[94] However, despite sources acknowledging a tourniquet risk of hastened freezing (frostbite) injury in both World Wars and in the Korean War, documentation of this risk was eliminated from at least one 1951 book.[98] Although the author was a military surgeon who discussed extreme cold weather and referenced a publication that reported that risk, the risk was absent from the book.[98]

A 1968 military field manual on cold weather noted at the end of a tourniquet paragraph: "Halting of circulation to the extremities is an invitation to frostbite."[99] A 1970 combat first-aid guideline for small, independent action forces included a note dealing with care after tourniquet application: "In extremely cold weather, protect any extremity with a tourniquet applied to prevent cold injury."[100] This note explicitly made thermal management of injured limbs a helping behavior within first aid, although it was intended for enactment by elite US Forces and not by the lay public. Also, as with other resources, no example of how to enact thermal protection was given. Frequency of advice about tourniquets risking cold injury decreased during and after the Vietnam War until such advice essentially ended after military reports in 2001.[101,102] One noted that, in treatment of a frozen limb to avoid further injury, use of a tourniquet should be avoided if, for example, a compress will suffice.[101] Notably, while the Vietnam-era guidance did explicitly note a tourniquet-frostbite association, the 2001 guides did not; they noted only that the tourniquet adds ischemic and compression trauma to the injured limb.

Although limb cooling risk is well established for tourniquets used routinely in research experiments and clinical surgery,[103–105] limb warming risk is also established,[106–110] albeit less known. During local cooling and heating in human limbs, the role of blood as heat source or heat sink is the principle underlying these risks[111] and their prevention. With a tourniquet effect, excess heat transferred to the limb causes local heating and risks heat injury[106–109] because blood cannot distribute the heat load to the rest of the body. Likewise in a historical review of a research council, a researcher was reported to have shown "that by occluding the circulation with a tourniquet, the same depth of burn could be produced in one fifth the time it took with the circulation intact,"[112] meaning that tourniquet-hastened burn occurred faster, perhaps in an experiment. Such inability to off-load excess heat is clinically relevant to rewarming cold limbs, such as by a fire, especially if the limb has frostbite or a tourniquet in use. Also, for a casualty in a rewarming bag while a tourniquet is in use, a heating device that is placed incorrectly or displaces from where it was put may plausibly risk a burned limb even if it has a cold injury. Cold-injured limbs have had local heat injury caused by such heaters.[113,114]

Tourniquet use guidelines in extreme cold weather are absent presently, whereas they existed previously. Guidelines need to be reviewed for possible updates to account for an association between tourniquet use and frostbite risk. A graded guidance based on end-user ability may be needed—for example, no update for lay first-aiders, a minor update for medics, and a major update for nurses and doctors. A new guideline for tourniquet uses in extreme cold weather is a suitable topic for a research priority list in combat casualty care. Treatment options and guidelines in how prehospital emergency caregivers are to thermally manage injured limbs is a topic in need of research and development—for example, how a paramedic is to keep a limb from freezing while not overheating it. Limb cooling in a warm environment has potential benefit because decreased metabolism lessens ischemic risk, so prehospital caregivers are to thermally manage injured limbs. With both heating and cooling, limb management is to account for both benefits and risks simultaneously while taking into consideration core temperature status.[115] The temperature safety limits and level of providers for such future guidelines are not yet set. The concept of evaporative heat loss from fresh wound surfaces or external hemorrhage in trauma may be important in extreme cold weather, and it may be an awareness gap in need of a fill. Countermeasures to excessive cooling of limbs may be developed as a list for potential instruction as either interventions or helping behaviors; these may be developed into information scaled to match end-user ability in caregiving. In casualties with cold limbs and first-aid tourniquets in use, tourniquet conversion may worsen core temperature decreases, and this may need specific research and development for emergency caregiving. The effect size of this "afterdrop" caused by tourniquet conversion needs study to allow it to be stratified to different ambient temperatures and the numbers of limbs with tourniquets used. If future investigators calculated the time (abscissa) difference between cooling rates (temperature, ordinate) with and without tourniquet use to or below supercooling, then the effect size of hastening frostbite can be estimated, and such a finding could inform caregiving.

Conclusions

The cause of frostbite is a sufficiently negative heat-transfer trend in local tissues, and tourniquet use may exacerbate the development of frostbite. Tourniquet-hastened frostbite exists as an association but not as cause and effect. Tourniquet use increases the risk of the cold causing frostbite by allowing faster and more reliable cooling. Such frostbite occurs in low frequency but at high severity because limb loss is a morbid complication to be avoided. Care providers above the level of lay public are to be warned that first-aid tourniquet use risks frostbite when cold weather is below 0°C (32°F).

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Author Contributions

Both authors participated in study conception and design, case count request and interpretation, search of literature and its interpretation, manuscript writing, and approval of its final version. JFK resourced, managed, and oversaw the study.

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- Prehospital Blood Transfusion Effect on Body Temperature
- Emergency Reflex Action Drills › Triage Algorithms for Prehospital Response MCIs
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