Prolonged tourniquet use in extremity trauma: What you need to know

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ABSTRACT: Routine tourniquet use has significantly improved early survival in both military and civilian settings for extremity hemorrhage in trauma patients. However, most supporting evidence revolves around short-duration tourniquet use stemming from trauma systems with rapid evacuation and early surgical care. Emerging military operations and austere civilian settings risk prolonged prehospital times, introducing uncertainty in the management of prolonged tourniquet application. These scenarios present high-risk situations for medical providers and potentially life-threatening complications for patients. Despite this, management strategies during these scenarios remain poorly defined. This review synthesizes current military and civilian literature to address key challenges in prolonged ischemia, including tourniquet conversion, decision-making surrounding limb salvage versus early amputation, and the pathophysiology and management of ischemia reperfusion injury. (*J Trauma Acute Care Surg* 2026;00:000–000. Copyright © 2026 Wolters Kluwer Health, Inc. All rights reserved.)

KEY WORDS: Prolonged tourniquet, austere critical care, prolonged casualty care, tourniquet conversion, ischemia reperfusion injury.

Extremity hemorrhage represents a potentially preventable cause of death in both military and civilian trauma patients. Widespread adoption of limb tourniquets has improved early survival, particularly in military conflicts where severe extremity hemorrhage is common and rapid hemorrhage control is essential.[1–5] Data from recent conflicts in the Middle East have demonstrated that tourniquet application at the point of injury was associated with a substantial reduction in mortality secondary to extremity hemorrhage, without a corresponding increase in limb loss.[2,6–8] These findings have led to broader incorporation into civilian trauma systems and prehospital care algorithms.[9–14]

However, these advances have largely been demonstrated in trauma systems with rapid evacuation, brief prehospital times, and reliable access to definitive surgical care. In contrast, emerging operational environments, such as near-peer conflict and large-scale combat operations (LSCO), are increasingly being defined by delayed evacuation, contested logistics, and the need for prolonged field care before surgical care.[15–17] Similar challenges can be encountered in civilian contexts such as rural or austere trauma, mass casualty incidents, and natural disaster settings, where transport delays and resource limitations may drastically prolong time to definitive care.[16,18–21]

These scenarios expose critical gaps in the current evidence base and clinical guidelines. While the safety and efficacy of tourniquets for early hemorrhage control remain largely unquestioned, considerably less certainty exists regarding the optimal management following application times exceeding two hours. Specifically, military and civilian clinicians may be confronted with complex decisions surrounding tourniquet conversion, tissue viability, and the systemic consequences of reperfusion. Reperfusion following prolonged ischemia represents a high-risk inflection point in management.[22–24]

Traditional paradigms surrounding limb salvage and amputation, as well as scoring metrics specifically designed to guide these decisions, were developed in resource-rich settings and may not be applicable under conditions of prolonged ischemia and limited critical care

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capacity.[25–28] Given these challenges, a pressing need for a practical, evidence-informed framework to guide the management of extremity trauma in the setting of prolonged tourniquet duration persists. At its core, management of prolonged tourniquet use requires balancing hemorrhage control, ischemic burden, and the systemic consequences of reperfusion. This narrative review aims to synthesize current military and civilian literature to focus on three critical domains: (1) considerations surrounding tourniquet conversion following extended application, (2) decision-making surrounding limb salvage versus early amputation in the context of prolonged ischemia, and (3) the pathophysiology and management of ischemia reperfusion injury, with an emphasis on strategies applicable to resource-constrained and austere settings. By integrating available evidence with contemporary operational realities, this review seeks to provide clinicians with a structured approach for these complex, life-threatening scenarios.

TOURNIQUET USE AND PROLONGED PREHOSPITAL TIME

Extremity tourniquets have become a life-saving cornerstone of modern hemorrhage control in both military and civilian trauma care.[10,13,29,30] Early experience from recent conflicts in the Middle East demonstrated a clear survival benefit associated with prehospital tourniquet application, particularly when applied before the onset of shock.[1–5,8] As such, tourniquet application has become widely adopted as the standard of care for early hemorrhage control in military and civilian extremity trauma.[13,31–34]

The safety profile of tourniquet use is closely linked to the duration of application.[22,35] Available military and civilian data consistently demonstrate that shorter durations (generally under 2 h) are associated with low rates of complications, whereas progressively longer application times result in increasing risk of nerve injury, muscle necrosis, compartment syndrome, and limb loss.[22,35–37] These risks reflect the time-dependent progression of ischemic injury to downstream tissues and the systemic consequences following reperfusion.[35] Although precise temporal thresholds remain incompletely defined throughout the literature, prolonged tourniquet use introduces risk of both local and systemic complications following reperfusion that render clinical decision-making particularly challenging.[22] Importantly, physiologic status and global injury burden likely create scenarios where strict tourniquet time thresholds differ between patient populations. Moreover, much of the existing literature comes from systems with rapid evacuation and early surgical care, limiting its generalizability to settings with prolonged or delayed prehospital transport.[20,21] Under these circumstances, the role of tourniquets evolves from a temporizing measure to a prolonged intervention and introduces complex clinical considerations regarding ischemia time and limb viability. These realities necessitate a reassessment of how best to manage the associated risk-benefit profile in traumatically injured patients with prolonged tourniquet times.

TOURNIQUET CONVERSION

Following tourniquet application for initial hemorrhage control, assessment for converting the tourniquet to a less restrictive method of hemorrhage control, such as a pressure dressing, has been advocated to limit the duration of limb ischemia.[38–41] All civilian medical personnel and military service members capable of applying tourniquets should also be trained in tourniquet reassessment and safe conversion when appropriate.[38] Multiple reports suggest that a substantial proportion of prehospital tourniquets are unnecessary in both military and civilian settings, ranging from 10% to 75.4%.[22,38,42–46] Therefore, it becomes critical that any qualified provider at the first receiving level of care or military service member assess and convert the tourniquet, if safe to do so, to prevent unnecessary complications.[40] This holds especially true in military settings, as evidenced by contemporary LSCO settings with prolonged evacuation times, where 75.4% of battlefield tourniquets were retrospectively deemed inappropriate and resulted in substantial preventable morbidity.[46]

In practice, tourniquet conversion requires a controlled, slow release (generally over 1–2 min, followed by at least 2 minutes of direct pressure to the wound with a moist dressing) to assess for ongoing hemorrhage while balancing the competing risks of rebleeding and reperfusion-associated complications. Conversion is generally recommended in patients who are hemodynamically stable, without traumatic amputation, and in whom the wound can be closely monitored for recurrent hemorrhage. Tactical Combat Casualty Care (TCCC) and Prolonged Field Care (PFC) guidelines recommend assessing for safe tourniquet conversion as soon as tactically feasible.[34,39] If a tourniquet is unable to be converted due to ongoing hemorrhage that cannot be controlled otherwise, repositioning from the "high and tight" initial placement to a deliberate approach by placing a tourniquet 2 to 3 inches proximal to the injury aligns with current recommendations.[34,38] This stepwise approach allows for minimization of ischemic exposure while maintaining hemorrhage control.

These recommendations reflect the well-established relationship between ischemia time and tissue injury[22,35] (Fig. 1). Contraindications to tourniquet conversion include traumatic amputation, persistent hemodynamic instability, inability to visualize or control the bleeding source, and major vascular disruption. During these instances, where tourniquet release poses a significant risk for exsanguination, maintaining the tourniquet presents the safest strategy. The management of patients who present with prolonged tourniquet times over 2 hours, where bleeding may be technically controllable but may have already experienced significant ischemic burden,

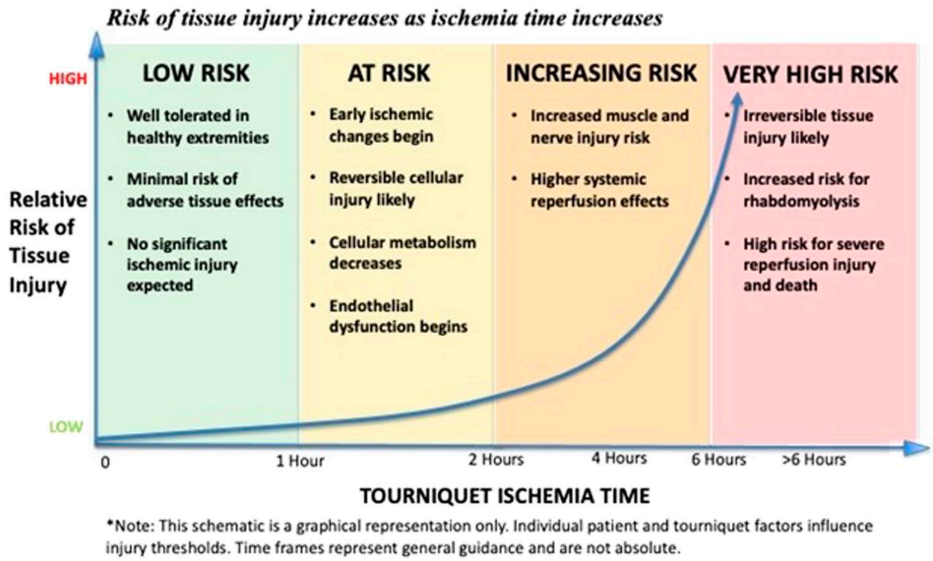

Figure 1. Ischemia time and risk of tissue injury with extremity tourniquet use.

represents a major clinical dilemma. Existing literature provides limited guidance on safe thresholds for conversion after prolonged application.[38–41]

Individualized approaches based on patient status, injury burden, underlying comorbidities, and available resources should be factored into the clinical decision-making process, and providers should have an in-depth understanding of the downstream sequelae of their decision. These factors form the basis for the subsequent decision-making regarding limb salvage versus early amputation and strategies to mitigate reperfusion injury.

LIMB SALVAGE VERSUS EARLY AMPUTATION IN PROLONGED ISCHEMIA

The decision to pursue limb salvage or proceed with early amputation represents one of the most challenging decisions during the management of severe extremity trauma, especially in scenarios of prolonged ischemia.[47,48] Traditional scoring systems, such as the Mangled Extremity Severity Score (MESS), were developed to assist with these decisions; however, their predictive accuracy has been inconsistent in modern practice.[25–27,47] These tools were derived from civilian trauma systems with rapid access to definitive care. As such, they do not account for prolonged ischemia times, combined blast or crush injuries, and the limited availability of resources common in combat operations and austere civilian settings. Thus, sole reliance on these tools is not recommended for these patients, and clinical judgment remains paramount.[47]

Preclinical and clinical data traditionally suggest that warm ischemia beyond 6 hours is associated with progressive, irreversible muscle necrosis, with accounts suggesting this process starts as early as the 3-hour mark[22,23,34,40] (Fig. 1). Generally, ischemia times < 2 hours are considered low risk, 2 to 6 hours are considered intermediate and should be viewed as context dependent, and > 6 hours represents a high risk of nonviability and systemic complications. These thresholds, however, are largely derived from controlled settings involving isolated vascular injury. Thus, they likely underestimate the degree of tissue damage in patients with concomitant hemorrhagic shock, soft tissue destruction, and crush injury. Within this population, the ischemic burden is amplified, resulting in a decreased likelihood of meaningful functional recovery following reperfusion. Orthopedic data further underscores the importance of associated factors such as extensive soft tissue loss, nerve injury, and compartment syndrome, which all independently predict poor functional outcomes following limb salvage.[49–51]

In the context of prolonged prehospital time, the decision to attempt reperfusion must carefully weigh the risks of systemic deterioration from ischemia-reperfusion injury. Reperfusion may precipitate severe metabolic derangements, including hyperkalemia and profound acidosis.[22,23] Recent data from the Russo-Ukrainian war demonstrate that extended tourniquet times are associated with increased rates of renal failure requiring renal replacement therapy, as well as significant rates of delayed amputation.[22] These findings support the consideration that early amputation, in select patients, represents a lifesaving intervention rather than a failure in care.

Prioritization of overall patient survival, while realistically evaluating the potential for functional limb recovery, should remain the key goal for clinicians.[28] A baseline practical algorithm for managing patients with prolonged tourniquet use is demonstrated in Figure 2.

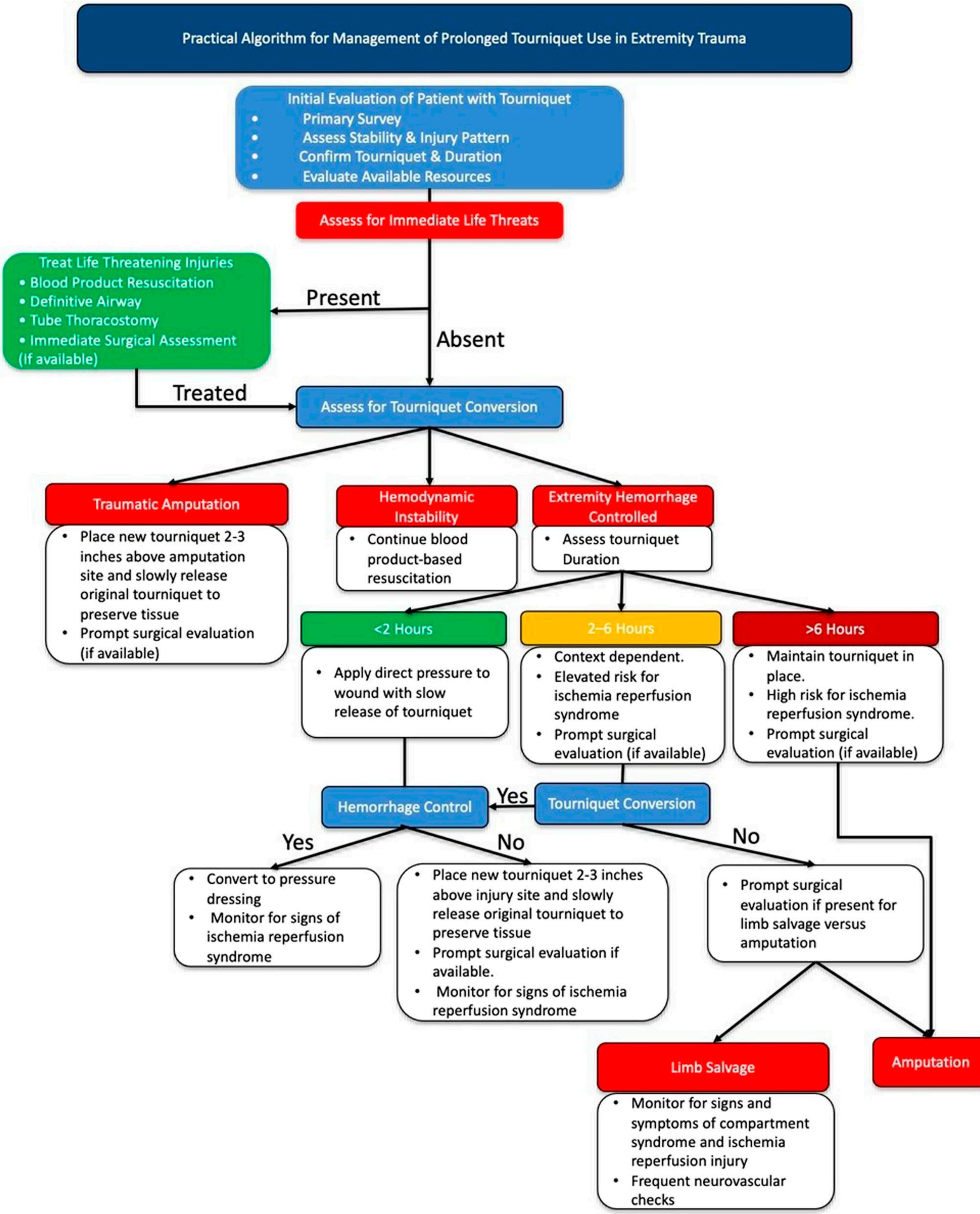

Figure 2. Practical algorithm for management of prolonged tourniquet use in extremity trauma.

Considerations favoring early amputation include prolonged ischemia time, evidence of nonviable muscle, combined venous and arterial injury, severe blast or crush injury, temperature dysregulation, ongoing hemodynamic instability, or limited capability to manage the complications associated with reperfusion (Table 1). In this setting, a tissue-preserving amputation as distal as possible remains the favorable approach, and formalization should occur only after assurance of hemodynamic stability and muscle viability in a staged manner.[52] While guillotine amputations are not traditionally recommended for mangled extremities in efforts to preserve any potentially viable tissue, guillotine amputation may be necessary in the setting of extended tourniquet times due to the well-demarcated ischemic boundary.

Conversely, limb salvage may be reasonable in patients with shorter or uncertain tourniquet times, adequate physiologic reserve, and the appropriate resources to monitor and manage ischemia reperfusion injury. Importantly, ongoing arterial hemorrhage in regions distal to the knee or elbow that are downstream from the extremity's primary arterial branch site are amenable to simple ligation when single vessel perfusion to the hand or foot is present, and there is no evidence of distal ischemia. This approach requires careful monitoring to include ongoing compartment and neurovascular checks, but may represent an amputation-sparing approach in select cases. These decisions should remain context-dependent and be individualized to the patient, with the understanding that the threshold for early amputation may be appropriately lowered when the sequelae of ischemia reperfusion injury cannot be safely managed.

MANAGEMENT OF ISCHEMIA REPERFUSION INJURY

Ischemia-reperfusion injury represents a critical crossroads for extremity trauma management following prolonged tourniquet use. Although restoration of blood flow is essential for limb salvage, the downstream cascade of inflammatory cytokines and byproducts of cellular destruction poses significant local and systemic risks.[22,23] The pathophysiology of ischemia reperfusion injury is extensively characterized throughout the literature, where reperfusion following controlled ischemia yields oxidative stress, endothelial dysfunction, and activation of inflammatory pathways.[53–56] Due to the compounding effects of polytrauma, traditional models likely underestimate the degree of severity that ischemia reperfusion injury may have in trauma patients. This holds especially true for combat-related injuries with severe bone and soft tissue injury distal to the battlefield tourniquet.

Clinically, ischemia reperfusion injury manifests as a spectrum from localized tissue damage to fulminant cardiovascular collapse.[23,56] Rhabdomyolysis remains a central component of this syndrome, where myocyte breakdown leads to markedly elevated creatine kinase levels and myoglobinuria, and frequently precipitates acute kidney injury.[22,23] Hyperkalemia and severe acidosis often develop rapidly following reperfusion and result in life-threatening, refractory cardiac arrhythmias, potentially causing death within minutes of tourniquet release.[56] Recent military data suggest that prolonged evacuation settings for these patients demonstrate a high rate of renal failure requiring renal replacement therapy.[22] Importantly, in both military and civilian austere settings, access to renal replacement therapy may be absent, and thus the clinical consequences of these metabolic derangements are amplified.

In this context, the management of ischemia reperfusion injury should be focused on risk mitigation, early recognition, and aggressive supportive care with readily available resources. Proactive planning remains essential before reperfusion. Several structured approaches have been proposed to operationalize this preparation. The "ABCDE" approach describes a structured approach consisting of alkalinization, blood pressure optimization, calcium administration, preparation for defibrillation, and electrolyte management before tourniquet release and is aimed to combat the systemic sequelae of ischemia reperfusion injury[57,58] (Fig. 3). Recently, Lukiianchuck et al.[22] proposed a two phased treatment algorithm approach from their experience in the Russo-Ukrainian war for managing patients with tourniquets in place for at least 4 hours. In preparation for potential reperfusion, peripheral nerve blocks or total

TABLE 1. Factors Favoring Primary Amputation Versus Limb Salvage Following Prolonged Extremity Tourniquet Use

Factors Favoring Primary Amputation	Factors Favoring Limb Salvage
Prolonged ischemia time	Shorter or uncertain ischemia time
Evidence of nonviable muscle or myonecrosis	Viable muscle, preserved tissue perfusion
Combined arterial and venous injury	Preserved distal perfusion through collateral or single-vessel flow
Severe blast or crush injury	Isolated distal arterial injury amenable to ligation
Extensive soft tissue destruction	Limited tissue destruction
Temperature dysregulation or hypothermia	Absence of distal ischemia
Ongoing hemodynamic instability	Hemodynamic stability
Progressive rhabdomyolysis or metabolic derangement	Adequate physiologic reserve
Inability to safely manage ischemia reperfusion injury	Ability to perform serial neurovascular and compartment assessments
Limited critical care, operative, or monitoring resources	Availability of critical care and reperfusion management resources
Low likelihood of meaningful functional recovery	Potential for meaningful functional recovery
	Acceptable anticipated rehabilitation potential

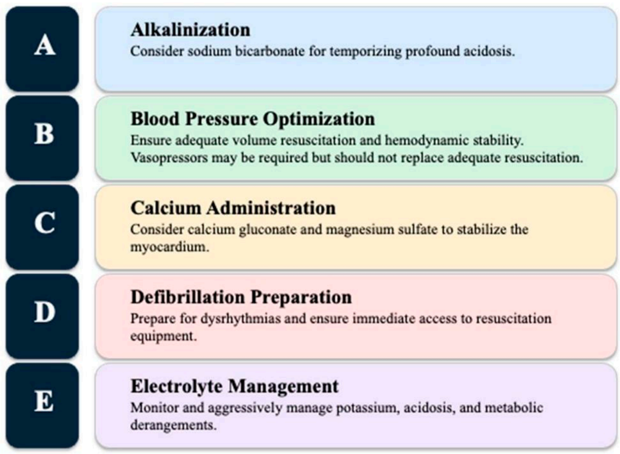

Figure 3. The "ABCDE" approach before extremity tourniquet release.

intravenous anesthesia were given, followed by a bolus of normal saline, calcium chloride or calcium gluconate, sodium bicarbonate, aminophylline, succinate gelatin solution (colloid). Following tourniquet release, fasciotomy is performed to assess the viability of the underlying muscle and, if deemed viable, a combination of mannitol, furosemide, and normal saline is given following reperfusion.[22] In a subsequent study during the same conflict comparing an early antirhabdomyolysis treatment, consisting of colloid, bicarbonate, and mannitol before tourniquet release followed by a normal saline bolus during reperfusion, with their conventional treatment strategy, consisting of a normal saline bolus before tourniquet release followed by colloid, bicarbonate, and mannitol, demonstrated that the antirhabdomyolysis treatment was independently associated with decreased odds for acute kidney injury requiring renal replacement injury, amputation, and mortality.[59] These protocols can be found in Table 2.

In prolonged care settings, several priorities emerge for clinical application. Management should include early volume resuscitation to mitigate the risk of renal injury. Preemptive treatment of reperfusion-associated hyperkalemia is critical, including administration of intravenous calcium gluconate and magnesium sulfate to promote cardiac stabilization. Central venous access should be obtained if feasible. In the presence of hyperkalemia, insulin with dextrose-containing fluids should be administered to promote temporary intracellular potassium shifts.[60] Sodium bicarbonate may be considered for temporizing profound metabolic acidosis; however, the evidence supporting routine use remains mixed.[60–62] Historically, urine alkalinization was proposed to reduce renal tubular injury, but due to inconsistent data, this has largely been abandoned in most clinical settings.[60,63–65]

Following reperfusion, continued high-volume resuscitation is often recommended to promote renal perfusion and facilitate myoglobin clearance.[60] Vasopressors

TABLE 2. Strategies for Mitigating Ischemia-Reperfusion Injury Following Prolonged Tourniquet Use

References	Setting (y)	Population	Pre-Tourniquet Release	Post-Tourniquet Release	Key Findings
Lukiianchuk et al.[22]	Ukrainian Austere Surgical Facility (2023–2024)	-74 combat casualties -Tourniquet >4 h	-Peripheral nerve block or TIVA -1 L NS -$CaCl_2$ 10 mL (10%) or Ca gluconate 30 mL -Aminophylline 10 mL (2%) -Succinate gelatin 500 mL (100 mL/h over 5 h)	-Mannitol 100 mL (15%) bolus, then 100 mL + furosemide 40 mg over 1 h -NS titrated to urine output (goal 200-300 mL/h)	-Mean tourniquet time 7.1 ± 2.9 h -Arterial injury 25.7% -Compartment syndrome 100% -Amputation 36.5% -RRT 70.8% -Mortality 6.8%
Lukiianchuk et al.[59]	Zaporizhzhia Military Hospital, Ukraine (2023)	-61 combat casualties -Prolonged lower extremity tourniquet	-Gelatin solution 500 mL (4%) -Sodium bicarbonate 100 mL (4%) -Mannitol 100 mL (15%)	-1 L NS	-Amputation 19.7% -RRT 36.1% -Mortality 11.5%
Weinrauch[58]	Expert recommendations (2023)	-Any patient -Tourniquet >2 h	-Hyperventilation -Sodium bicarbonate 50 mL (8.4%) -Blood pressure optimization -Ca gluconate 10 mL (10%) -Telemetry/defibrillator pads -Consider insulin (10 U) + D50 (50 mL) -Active warming	—	—

Ca, calcium; $CaCl_2$, calcium chloride; D50, 50% dextrose in water; NS, normal saline; RRT, renal replacement therapy; TIVA, total intravenous anesthesia; U, units.

may be required for refractory shock, but should not replace adequate initial resuscitation. Crystalloid has traditionally represented the resuscitation agent of choice; though, in polytrauma patients this may not be ideal and blood product-based strategies, if available, may be the more appropriate resuscitative agent dependent on the scenario.[66] Since any initial antibiotics given will not adequately penetrate tissue distal to the tourniquet, antibiotics should be redosed following reperfusion, especially with open fractures, extensive soft tissue damage, or when fasciotomies or other surgical procedures are performed.[67] Finally, in trauma patients with concerns for hemodynamic instability or ongoing bleeding, the use of diuretics to augment myoglobin clearance should be withheld and utilized only in settings once hemodynamic stability has been achieved, adequate resuscitative fluids are present if needed, and their use is recommended only for treating volume overload, not promoting myoglobin clearance from rhabdomyolysis or preventing progression of kidney injury.[64,66,68]

In a recent single-center military study from the Russo-Ukrainian War, ischemia reperfusion injury secondary to prolonged tourniquet use demonstrated a 70.8% need for renal replacement therapy.[22] In the absence of renal replacement therapy, preemptive and early management strategies of metabolic complications and appropriate resuscitation become paramount. When renal replacement therapy is not anticipated to be available for a prolonged period, the threshold for early amputation may be appropriately lowered. These considerations should, therefore, remain central to clinical planning and decision-making of military providers in future near-peer conflicts and large-scale combat operations where evacuation routes are contested. This also holds true for civilian clinicians receiving patients with prolonged prehospital times or practicing in remote, austere, or low-resourced settings. Accordingly, reperfusion should not be viewed as benign or obligatory, but as a high-risk intervention with immediate life-threatening implications requiring deliberate preparation, access to operative and critical care capabilities, and situation-dependent risk assessment.

SPECIAL CONSIDERATIONS

The management of extremity trauma in the setting of prolonged ischemia is further complicated by numerous injury and situation-specific factors that influence both limb and life-saving decisions.[28] Compartment syndrome represents a critical and frequently encountered complication in these settings, with a recent single-center report demonstrating tourniquet times >4 hours being associated with a 100% rate of compartment syndrome.[22] Not only do crush injuries, intramuscular hemorrhage, and local tissue destruction pose a risk for compartment syndrome, but the capillary leak, interstitial edema, and resultant elevated compartment pressures associated with reperfusion of ischemic muscle may also exacerbate tissue injury and compromise perfusion.[23,48,69] As such, a low threshold for fasciotomy is recommended when limb salvage is pursued. Nevertheless, in austere or resource-constrained environments, a decision to perform fasciotomy must account for the capabilities available to provide definitive wound management, repeat debridement, and infection control. Thus, prophylactic fasciotomy in the absence of clear clinical indications may expose patients to significant downstream morbidity if timely evacuation to higher levels of care is not available.

Important anatomic differences exist between upper and lower extremity injuries. The lower extremity has greater muscle mass and metabolic demand, resulting in an increased susceptibility to ischemia-reperfusion injury and systemic complications.[23,70] Conversely, upper extremity injuries may tolerate longer periods of ischemia compared with the lower extremity. Differences in ischemic tolerance between upper and lower extremities remain poorly defined, and functional outcomes remain highly dependent on nerve injury and soft tissue loss.[49] Furthermore, upper extremity amputation may have greater implications on subsequent quality of life compared with lower extremity amputation, although both result in significant lifestyle changes. Thus, the decision to amputate should not be made lightly, nor without collaboration when possible.

The overall patient context must also be considered. In polytrauma patients, especially those with concomitant severe traumatic brain injury, reperfusion-induced metabolic derangements and hemodynamic instability pose a risk for serious exacerbation of secondary brain injury.[71] Moreover, reperfusion following tourniquet times of ≥60 minutes has been associated with increases in intracranial pressure, although it remains unclear what clinical impact this may have.[72,73] In such cases, prioritization of functional neurologic outcomes may influence clinicians to forego attempts at limb salvage. Similarly, crush, blast, and high velocity ballistic injuries, which commonly occur in military operations and civilian disaster scenarios, introduce a significant burden of unseen muscle damage and release of systemic toxicities that may further amplify the clinical manifestations associated with reperfusion. These factors underscore the importance of assessing the overall patient's physiologic and clinical status, as opposed to evaluating the extremity injury in isolation.

Unique challenges arise in prolonged field care environments, where surgical capability may be absent for prolonged periods of time.[15] In these situations, medics and nonsurgeons will be required to manage tourniquets, monitor for evolving ischemia, and make critical decisions regarding tourniquet conversion or maintenance without access to operative intervention. The decision to convert the tourniquet must balance the recognition that reperfusion is not a benign intervention and may be immediately life-threatening, whereas maintenance of the tourniquet for over 6 hours will likely lead to amputation. In extreme resource-limited environments, considerations for alternative therapies such as peritoneal dialysis have been described for acute kidney injury; however, the applicability of this approach following acute traumatic injury is unproven and is likely limited by logistical constraints and potential infectious complications.[74] Scenarios involving prolonged field care management necessitate dynamic, context-dependent decision-making. Simple, durable strategies in these scenarios should emphasize maintaining effective hemorrhage control, ongoing assessment of limb viability, early recognition of clinical deterioration, and preparation for subsequent physiologic decompensation.

Finally, patient-specific factors influence risk and should be considered during the decision-making process. Pediatric patients may demonstrate greater physiologic reserve and potential for recovery; however, a paucity of data exists in this unique population, and management is typically extrapolated from adult populations. Conversely, elderly patients or those with significant comorbidities may have a decreased tolerance for prolonged ischemia and the systemic consequences of reperfusion.[75] In particular, diabetes mellitus, peripheral arterial disease, chronic kidney disease, coronary artery disease, and other manifestations of systemic atherosclerosis may impair baseline microvascular perfusion and collateral blood flow, thereby increasing susceptibility to ischemic injury and the metabolic consequences of reperfusion.[76,77] Furthermore, these patients frequently demonstrate impaired wound healing, increased risk of infection, and reduced functional recovery following limb salvage attempts.[78,79] These comorbidities, which are highly relevant in civilian trauma populations, as well as additional factors such as tobacco use, vasopressor requirements, and preexisting neuropathy, should factor into decisions regarding tourniquet duration tolerance, reperfusion management, and consideration for early amputation versus limb salvage.

FUTURE CONSIDERATIONS

Despite significant advancements in extremity trauma care, substantial evidence gaps remain regarding the management of prolonged tourniquet application. High-quality data defining safe thresholds for tourniquet duration, optimal timing for conversion, and the decision-making surrounding limb salvage versus amputation remain limited. Much of the current data stems from retrospective analyses or is extrapolated from settings with short evacuation timeframes, rapid access to surgical care, and robust critical care capabilities. High-quality data from large-scale combat operations and civilian analogs such as rural trauma systems and disaster response remain largely absent within the literature.

Emerging research has increasingly focused on mitigating reperfusion injury. These efforts largely stem from experimental and translational studies that focus on reducing oxidative stress, modulating inflammatory pathways, and attenuating endothelial dysfunction.[55,80] In addition, growing interest in strategies applicable to austere settings, such as controlled or staged reperfusion, optimizing resuscitation protocols in rhabdomyolysis, and pharmacologic agents targeting metabolic derangements, has recently been explored.[59,81–83]

Operational and system-level innovations also warrant consideration. The paradigm of rapid evacuation to definitive levels of care may not be feasible in all scenarios, and consideration of forward-deployed mobile medical capabilities in military and civilian environments may result in decreased tourniquet duration. The deployment of physician-led trauma teams into the prehospital space offers the potential to facilitate earlier decision-making regarding tourniquet conversion, limb viability, risks of reperfusion, and perhaps even temporary reperfusion if the appropriate assets are present. Similar teams have demonstrated success in select military and civilian settings; however, their development and implementation require serious logistical considerations that may not be scalable in all environments.[16,84] Importantly, improvements in caring for patients with prolonged extremity ischemia will depend not only on advances in clinical management, but also on developing adaptable systems of care that align with available resources.

CONCLUSION

The fundamental paradigms that have traditionally guided both military and civilian extremity trauma management are insufficient in the setting of prolonged tourniquet duration. The life-saving benefit of tourniquet use remains well established, yet prolonged ischemia introduces complex, life-threatening challenges. These scenarios require clinicians to think beyond protocolized approaches and adopt a context-driven framework prioritizing survival and realistically assessing the possibility for functional limb salvage. These decisions must balance the risks of physiologic collapse, renal failure, and multiorgan dysfunction. This holds especially true in environments where advanced supportive care is unavailable. Reperfusion should not be assumed to be benign, and in some environments, avoiding it through early amputation represents the safest strategy. In this context, the decision is no longer simply whether to restore perfusions, but whether the patient can survive its consequence. Ultimately, improving outcomes will require continued investigation into prolonged ischemia, development of pragmatic strategies for resource-limited environments, and evolution of trauma systems capable of addressing delayed care.

AUTHORSHIP

D.L., R.H., J.M., S.A., E.K., E.S., and T.L. contributed to study design and performed the literature search. D.L., R.H., J.M., S.A., E.K., E.S., T.L., M.E., K.I., and J.H. critically interpreted the results and critically revised the manuscript. D.L., R.H., and E.K. drafted the original manuscript.

DISCLOSURE

J.H. is a cofounder and on the Board of Directors of Decisio Health, on the Board of Directors of QinFlow and Zibria, a Coinventor of the Junctional Emergency Tourniquet Tool, an adviser to Aspen Medical, and Wake Forest Institute of Regenerative Medicine. J.M. is a cofounder of the Behind The Knife Podcast. D.L., R.H., J.M., S.A., E.K., E.S., and T.L. are all active duty or reserve military members; however, the views in this paper are those of our own and do not reflect the views of the government or Department of Defense. The remaining authors declare no conflicts of interest. All JTACS Disclosure forms for the authors have been supplied and are provided as Supplemental Digital Content (http://links.lww.com/TA/F536).

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