Management of Crush Syndrome Under Prolonged Field Care

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Introduction to the Prolonged Field Care Prehospital Clinical Practice Guideline Series

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THIS FIRST CLINICAL PRACTICE GUIDELINE (CPG) was produced through a collaboration of the SOMA Prolonged Field Care Working Group (PFCWG) and the Joint Trauma System (JTS) at the U.S. Army Institute of Surgical Research (USAISR) in San Antonio. Of note, this effort is the result from requests for information and guidance through the PFC website (PFCare.org) and from the Joint Special Operations Medical Training Center instructors located at Fort Bragg, North Carolina.

We are excited to introduce the first prehospital (presurgical) CPG specifically aimed at providing guidance beyond the initial evaluation and treatment of casualties in a PFC operational environment. This and future CPGs are aimed at serious clinical problems seen less frequently (e.g., crush injury, burns) or where further advanced practice recommendations are required (e.g., pain and sedation recommendations beyond TCCC recommendations, traumatic brain injury).

We hope that this collaboration of experienced operational practitioners and true subject matter experts, operating under the guidance set forth in past JTS CPG editorial standards, will bring practical and applicable clinical recommendations to the advanced practice first responders and Role 1 providers in the field. For feedback or additional input, please visit PFCare.org.

This Role 1, prolonged field care (PFC) guideline is intended to be used after Tactical Combat Casualty Care (TCCC) Guidelines when evacuation to higher level of care is not immediately possible. A provider of PFC must first and foremost be an expert in TCCC. This Clinical Practice Guideline (CPG) is meant to provide medical professionals who encounter crush syndrome in austere environments with evidence-based guidance for how to manage the various aspects of crush injury care and monitoring. Recommendations follow a "minimum," "better," "best" format that provides alternate or improvised methods when optimal hospital options are unavailable.

Crush syndrome is a life and limb-threatening condition that can occur as a result of entrapment of the extremities accompanied by extensive damage of a large muscle mass. It can develop following as little as 1 hour of entrapment. Effective medical care is required to reduce the risk of kidney damage, cardiac arrhythmia, and death.

Crush syndrome is a reperfusion injury that leads to traumatic rhabdomyolysis. Reperfusion results in the release of muscle cell components, including myoglobin and potassium, that can be lethal. Myoglobin release results in rhabdomyolysis, with risk of kidney damage. Hyperkalemia can cause kidney damage and cardiac arrhythmias. Calcium is taken up by injured muscle cells and this can cause hypocalcemia, contributing to cardiac arrhythmias. The risks are increased with large areas of tissue crushed (one or both lower extremities) and the length of time the casualty is pinned prior to extrication. The primary treatment is aggressive fluid administration.

Reperfusion after prolonged tourniquet application (>2 hours), extremity compartment syndrome, and severe limb trauma involving blunt trauma can also result in rhabdomyolysis by the same mechanisms as crush syndrome, and the treatment is the same.

Telemedicine: Management of crush syndrome is complex. Establish telemedicine consult as soon as possible.

Fluid Resuscitation

The principles of hypotensive resuscitation according to TCCC DO NOT apply in the setting of extremity crush injury requiring extrication. However:

In the setting of a crush injury associated with noncompressible hemorrhage, aggressive fluid resuscitation may result in increased hemorrhage. Balancing the risk of uncontrolled hemorrhage against the risk of cardiotoxic levels of potassium should ideally be guided by expert medical advice (in-person or telemedicine).

Fluids[1–5]

Goal: Correct hypovolemia to prevent myoglobin injury to the kidneys and dilute toxic concentrations of potassium to reduce risk of kidney damage and lethal arrhythmias.

- **Best:** IV crystalloids
  - o Start intravenous (IV) or intraosseous (IO) administration IMMEDIATELY (before extrication). Rate and volume: initial bolus, 2L; initial rate: 1L/h, adjust to urine output (UOP) goal of >100–200mL/h (see below)
- **Better:** oral intake of electrolyte solution
  - o Sufficient volume replacement may require "coached" drinking on a schedule.[6]
- **Minimum:** rectal infusion of electrolyte solution
  - o Rectal infusion of up to 500mL/h can be supplemented with oral hydration.[6,7]

Life-threatening hyponatremia can result from large-volume administration of plain water. If using oral or rectal fluids because of unavailability of IV fluids or access, they must be in the form of a premixed or improvised electrolyte solution to reduce this risk.[6]

Examples of mixed or improvised electrolyte solutions include the following:

- World Health Organization (WHO) oral rehydration salts (ORS): preferred
- Pedialyte® (Abbott Laboratories, https://pedialyte.com)
- Per 1L water: 8 tsp sugar, 0.5 tsp salt, 0.5 tsp baking soda
- Per quart Gatorade® (Stokely-Van Camp Inc, www.gatorade.com): 0.25 tsp salt, 0.25 tsp baking soda

Monitoring

Goal: maintain high UOP, detect cardiotoxicity, adequate oxygenation and ventilation, avoid hypotension, trend response to resuscitation. Document blood pressure (BP), heart rate (HR), fluid input, urine output (UOP), mental status, pain, pulse oximetry, and temperature on a flowsheet.

Urine Output[8,9]

Goal: UOP of 100–200mL/h. The fluid rate should be adjusted to maintain this level of UOP.

- **Best:** place Foley catheter.
- **Minimum:** capture urine in premade or improvised graduated cylinder (e.g., Nalgene® bottle [Thermo Fisher Scientific, nalgene.com]).
- Maintain goal UOP until myoglobin can be monitored and normalized.
  - o If UOP is below goal at IV fluid rate of 1L/h for >2 hours, kidneys may be damaged and unable to respond to fluid resuscitation. Consider:

Teleconsultation, if available

- Decreasing the fluid rate to reduce risks of volume overload (e.g., pulmonary edema)
- Hemorrhage or third spacing may cause hypovolemia. Consider:
  - o Increasing the fluid rate

Urine Myoglobin[10–13]

Goal: Monitor for worsening condition

- **Best:** laboratory monitoring of urine myoglobin
- **Better:** urine dipstick monitoring of erythrocyte/hemoglobin (Ery/Hb)[10]
- Urine dipstick Ery/Hb will be positive in patients with myoglobinuria.
- **Minimum**: monitor urine color. Darker urine (red, brown, or black), either consistently or worsening over time, is associated with increasing myoglobinuria and increased risk of kidney damage.

Hyperkalemia and Cardiac Arrhythmias

Release of potassium from tissue damage and kidney damage can result in hyperkalemia (5.5mEq/L), resulting in life-threating cardiac arrhythmias or heart failure[14–17]

Goal: Monitor for life-threatening hyperkalemia

- **Best:** laboratory monitoring of potassium levels, 12-lead electrocardiogram (ECG), cardiac monitor (e.g., ZOLL® [ZOLL Medical Corp, www.zoll.com]; Tempus Pro™ [Remote Diagnostic Technologies, http://www.rdtltd.com])
- **Better:** laboratory monitoring of potassium levels, cardiac monitor (e.g. ZOLL®, Tempus Pro™)
- **Minimum:** close monitoring of vital signs and circulatory examination
- Frequency: every 15 minutes for initial 1–2 hours
- Decrease frequency to every 30 minutes, then hourly if stable or if urine is clearing
- Monitor for premature ventricular contractions (PVCs; skipped beats), bradycardia, decreased peripheral pulse strength, hypotension
- Specific ECG signs: **sinus bradycardia (primary sign)**; peaked T waves, lengthening PR interval (early signs),

prolonged QRS interval, PVCs or runs of ventricular tachycardia, conduction block (bundle branch, fascicular)
- If PVCs become more frequent, the patient develops bradycardia, peripheral pulse strength decreases, or potassium levels are >5.5mEq/L **or rising,** treat urgently for hyperkalemia.
- Insulin and 50% dextrose (D50); calcium gluconate; albuterol (see treatment instructions below)


Consider teleconsultation or more urgent evacuation to facility with laboratory and ECG monitoring, if possible.
- Use tourniquets to isolate limb(s) (see Tourniquets below)

Treatments for Cardiac Arrhythmias Due to Hyperkalemia

Treat if potassium level is >5.5mEq/L **or** there are cardiac arrhythmias (see above). Note that a normal ECG may occur in patients with hyperkalemia.

Goal: Restore normal ECG/prevent fatal cardiac complications

Treatment for Hyperkalemia
- **Best:** calcium gluconate; insulin + D50; albuterol; sodium polystyrene sulfonate
- **Better:** calcium gluconate; insulin + D50
- **Minimum:** any individual or combination of treatments, as available
- *Calcium gluconate (calcium replacement):* Increases serum calcium to overcome the effect of hyperkalemia on cardiac function.[18] Alternate: may use calcium chloride, which is more irritating when administered via peripheral IV.
  - o Treatment instructions: Administer 10 mL (10%) calcium gluconate or calcium chloride IV over 2–3 minutes. Onset of effect: immediate. Duration of action: 30–60 minutes.
- *Insulin and glucose:* Insulin is given to lower the serum potassium level by driving it back into the cells; glucose is given to prevent hypoglycemia.[18]
  - o Treatment instructions: give 10 units of regular insulin followed immediately by 50mL of D50. Onset of effect: 20 minutes. Duration of action: 4–6 hours.
- *Albuterol:* Lowers serum potassium level by driving it back into the cells; effect is additive with insulin.[19]
  - o Treatment instructions: Administer 12mL of albuterol sulfate inhalation solution, 0.083% (2.5mg/3mL) in nebulizer. Onset of effect: 30 minutes. Duration of action: 2 hours.
- *Sodium polystyrene sulfonate (Kayexalate®; Concordia Pharmaceuticals, http://concordiarx.com):* Lowers serum potassium level by removing potassium from the gut.[18]
  - o Treatment instructions: 15–30g suspended in 50–100mL liquid. Oral or rectal. Onset of action: >2 hours. Duration of action: 4–6 hours.
- *Bicarbonate:* Although routinely recommended as mainstay treatment to reduce kidney damage by raising the urine pH and diminishing intratubular pigment cast formation, and uric acid precipitation; to correct metabolic acidosis; and to reduce potassium levels, there is no clear evidence that bicarbonate reduces kidney damage[20], and the effect of reducing potassium is slow and unsustained.[21]


Sodium polystyrene sulfonate removes potassium from the body. All other treatments temporarily lower potassium by shifting it out of circulation and into the cells. Continue to monitor and repeat treatment when needed.

Tourniquets for Management of Crush

Tourniquets may delay the life-threating complications of a reperfusion injury if immediate fluid resuscitation or monitoring is not initially available. Consider tourniquet placement for crush injury before extrication if the length of entrapment exceeds 2 hours and crush injury protocol cannot be initiated immediately.[22–24]

Goal: Delay acute toxicity until after fluid resuscitation and monitoring are available.
- **Best:** Apply two tourniquets side by side and proximal to the injury immediately before extrication
- **Minimum**: Apply two tourniquets side-by-side proximal to the injury immediately after extrication
- Initiate crush injury protocol before loosening tourniquet, and then only if the patient meets criteria for tourniquet conversion or removal given in the TCCC guideline


A limb that is cool, insensate, tensely swollen, and pulseless is likely dead. Patient may develop shock and kidney damage, and may die. Consider fasciotomy. If no improvement, place two tourniquets side by side and proximal to the injury and do not remove. Amputation anticipated.

Fasciotomy

Extremity compartment syndrome must be anticipated with crush injury and reperfusion injury.[25–27]

Goal: Decompress muscle, restore blood flow.
- **Best:** Perform fasciotomy (only if there are clinical signs of compartment syndrome). The earliest sign is limb swelling with severe pain with or without passive motion, persisting despite adequate analgesia, followed by paresthesia, pallor, paralysis, poikilothermia, and pulselessness.

Appendix B *Monitoring and Management Considerations Over Time*

			Phase 1 Entrapment	Phase 2 Extrication	Phase 3 Immediately Following Extrication	Phase 4 Prolonged Field Care
Fluids						
	Best	IV or IO crystalloids	Initial bolus: 2L, continue 1L/h	Continue 1L/h	Titrate to UOP 100–200mL/h	Titrate to UOP 100–200mL/h
	Better	Oral electrolyte solution	Continue	Continue	Continue. Goal UOP 100–200mL/h	Continue. Goal UOP 100–200mL/h
	Minimum	Rectal electrolyte solution	Continue	Continue	Continue. Goal UOP 100–200mL/h	Continue. Goal UOP 100–200mL/h
Telemedicine: consult on management						
Monitoring: 15-minute to hourly vital signs, examination, urine output documented on flowsheet						
Vital signs						
	Best	Portable monitor with ECG	Record every 15 minutes	Record every 15 minutes	Record every 15 minutes	Record every 1 hour
	Better	Check intermittent vital signs	Every 15 minutes	Every 15 minutes	Every 15 minutes	Every 1 hour
	Minimum	Monitor pulse and mental status	Every 15 minutes	Every 15 minutes	Every 15 minutes	Every 1 hour
UOP	Best	Place Foley catheter	N/A	N/A	Record UOP every 1 hour	Record UOP every 2 hours
	Minimum	Capture urine in premade or improvised graduated cylinder				
Urine myoglobinuria	Best	Laboratory monitoring	N/A	N/A	N/A	Every 6 hours
	Better	Assess urine color (red, brown, or even black)				
	Minimum	Dark urine (red, brown, or even black)				
Potassium and cardiac arrhythmia	Best	Laboratory monitoring of potassium levels	N/A	N/A	Check	Every 4–6 hours
		12-lead ECG	N/A	N/A	Check	Every 4–6 hours
	Better	Laboratory monitoring of potassium levels	N/A	N/A	Check	Every 4–6 hours
		3–5 lead ECG	Initiate	Continue	Continue	Continue
	Minimum	Close monitoring of vitals and circulatory examination	Initiate	Continue	Continue	Continue

Treatments for Hyperkalemia (>5.5mEq/L) or Cardiac Arrhythmia						
Calcium gluconate (10%)	Best	10mL IV over 2–3 minutes	N/A	N/A	Monitor; repeat as required	
Insulin (regular) and D50		10 units IV push + 50mL D50	N/A	N/A		
Albuterol (2.5mg/3mL vial)		10mg (4 vials) in nebulizer	N/A	N/A		
Sodium polystyrene sulfonate (Kayexalate)		15–30g suspended in 50–100mL liquid, oral or rectal	N/A	N/A		
Calcium gluconate 10% Alternate: calcium chloride 10%	Better	10mL IV over 10 minutes	N/A	N/A		
Insulin (regular) and D50		10 units IV push + 50mL D50	N/A	N/A	Monitor; repeat as required	
Any individual or combination of above, as available	Minimum	See above	N/A	N/A		
Management of Injured Extremity						
Extremity compartment syndrome	Best	Clinical assessment • 6 Ps* • Rigid compartment	—	—	Fasciotomy: only if qualified medical personnel or teleconsultation available	
	Minimum				Cool limb (evaporative or environmental cooling, no ice/snow)	
Tourniquet (for crush management)	Best	If adequate fluids are unavailable, or arrhythmia cannot be managed during entrapment and extrication	If entrapment time >2 hours, consider tourniquet. Place two tourniquets side by side and proximal to the injury	If the patient meets criteria for tourniquet conversion or removal, and fluids are available, initiate crush injury protocol before loosening tourniquet.		
Tourniquet (for irreversible injury)		A limb that is cool, insensate, tensely swollen, and pulseless is likely dead. Patient may develop shock and kidney damage, and may die.				Consider fasciotomy. If no improvement, place two tourniquets side by side and proximal to the injury. Amputation anticipated
Pain						
			Per TCCC	Per TCCC	Per TCCC	Refer to Pain/sedation CPG
Infection control						
Antibiotics	Best	Portable monitor with ECG	Ertapenem, 1g IV/day (1g, 10mL saline or sterile water)			
	Better	Check intermittent vital signs	Cefazolin, 2g IV every 6 to 8 hours; clindamycin (300–450mg by mouth three times daily or 600mg IV every 8 hours); or moxifloxacin (400mg/day; IV or by mouth)			
	Minimum	Monitor pulse and mental status	—	—	Ensure wounds cleaned and dressed, and hygiene of wounds and patient optimized to the extent possible given environment.	

N/A, not applicable; UOP, urine output. *6 Ps: Pain persisting despite adequate analgesia is most important symptom, followed by *paresthesia, pallor, paralysis, poikilothermia, pulselessness*

Only if qualified medical personnel or teleconsultation (ideally with real-time video capability) available.
  - o Then only if wound care available.
  - o Regional anesthesia with nerve block or IV sedation required.
- **Minimum:** Cool limb to reduce extremity edema (evaporative or environmental cooling only, do not pack limb in ice or snow because of risk of further tissue damage).
- **Pain management:** Refer to TCCC Guidelines for analgesia on the battlefield.[28]

Infection

For infection due to associated wounds and not crush injury itself, follow the Joint Theater Trauma System Infection Control Guidelines: "Prevent Infection in Combat-Related Injuries for Extremity Wounds."[29]

Goal: Prevent infection.
- **Best:** Ertapenem, 1 gm IV/day (1g, 10 ml saline or sterile water)
- **Better:** Cefazolin, 2g IV every 6 to 8 hours; clindamycin (300–450 mg by mouth three times daily or 600 mg IV every 8 hours); or moxifloxacin (400 mg/day; IV or by mouth)
- **Minimum:** Ensure wounds are cleaned and dressed, and hygiene of wounds and patient optimized to the extent possible given environment.

Two appendices accompany this article: Appendix A presents a summary of fluid and equipment planning considerations; Appendix B comprises three tables presenting monitoring and management considerations relative to time.

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Appendix A *Fluid and equipment planning considerations*

Best:
• Fluids: IV fluid to provide 1L/h for 24 to 48 hours (depending on evacuation availability) • Equipment: ECG, laboratory tests for serum potassium and urine myoglobin, Foley catheter with graduated collection system, tourniquets • Medications: hyperkalemia*: calcium gluconate (5 x 10mL vial or Bristojet), insulin: 1 vial Humulin R (500 units; Lilly USA, www.humulin.com), D50 (120mL), albuterol (24 vials), Kayexalate (360g; Concordia Pharmaceuticals, http://concordiarx.com) • Pain: refer to Analgesia, Sedation Clinical Practice Guidelines (CPG) • Antibiotics: ertapenem • Monitoring: Continuous monitoring with portable monitor; 15-minute to hourly vital signs, examination, urine output documented on flowsheet
Communications: real-time video telemedicine consultation
Better:
• Fluids: IV fluid to provide 1L/h for 24 to 48 hours • Equipment: Dipstick urine tests to monitor urine, graduated container to monitor urine output, tourniquets • Medications: hyperkalemia: calcium gluconate (5 x 10mL vial or Bristojet), insulin: 1 vial Humulin R (500 units), D50 (120mL) • Pain medications • Antibiotics • Monitoring: 15-minute to hourly vital signs, examination, urine output documented on flowsheet
Communications: telephone, possibly e-mail telemedicine consultation
Minimum:
• Fluids: IV fluid for initial bolus resuscitation (2L), then oral or rectal fluid resuscitation with commercial or improvised electrolyte solution • Equipment: Guaduated container to monitor urine output, tourniquets • Medications: hyperkalemia: calcium gluconate (5 x 10mL vial or Bristojet) • Pain medications • Antibiotics • Monitoring: 15-minute to hourly vital signs, examination, urine output documented on flowsheet or other written format
Communications: telemedicine by telephone

*Calculated quantities based on treating one patient for 48 hours.

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