Management of Crush Syndrome Under Prolonged Field Care

This Role 1 prolonged field care (PFC) guideline 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.

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INTRODUCTION

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 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. Kidney damage leads to hyperkalemia and eventually 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.

For feedback or additional input on this CPG, please visit PFCare.org.

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).

FLUIDS¹⁻⁵

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.
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- **Best:** IV crystalloids
  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.
  Sufficient volume replacement may require “coached” drinking on a schedule.\(^6\)

- **Minimum:** rectal infusion of electrolyte solution.
  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, ensure 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.
  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:** 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-threatening 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
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- **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. Alternate: may use calcium chloride, which is more irritating when administered via peripheral IV.

  **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.

  **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.

  **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.

  **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, and the effect of reducing potassium is slow and unsustained.

- 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-threatening 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.

**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.

- Only if qualified medical personnel or teleconsultation (ideally with real-time video capability) available.
  - Then only if wound care available.
  - 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 oxifloxacin (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 summarizes monitoring and management considerations relative to time.
REFERENCES


## Management of Crush Syndrome Under Prolonged Field Care

### APPENDIX A: FLUID AND EQUIPMENT PLANNING CONSIDERATIONS

<table>
<thead>
<tr>
<th>Best</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluids:</strong> IV fluid to provide 1L/h for 24 to 48 hours (depending on evacuation availability)</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment:</strong> ECG, laboratory tests for serum potassium and urine myoglobin, Foley catheter with graduated collection system, tourniquets</td>
<td></td>
</tr>
<tr>
<td><strong>Medications:</strong> hyperkalemia*: calcium gluconate (5 x 10mL vial or Bristojet), insulin: 1 vial Humulin R (500 units; Lilly USA, <a href="http://www.humulin.com">www.humulin.com</a>), D50 (120mL), albuterol (24 vials), Kayexalate (360g; Concordia Pharmaceuticals, <a href="http://concordiarx.com">http://concordiarx.com</a>)</td>
<td></td>
</tr>
<tr>
<td><strong>Pain:</strong> refer to Analgesia, Sedation Clinical Practice Guidelines</td>
<td></td>
</tr>
<tr>
<td><strong>Antibiotics:</strong> Ertapenem</td>
<td></td>
</tr>
<tr>
<td><strong>Monitoring:</strong> Continuous monitoring with portable monitor; 15-minute to hourly vital signs, examination, urine output documented on flowsheet</td>
<td></td>
</tr>
</tbody>
</table>

**Communications:** real-time video telemedicine consultation

<table>
<thead>
<tr>
<th>Better</th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Fluids:</strong> IV fluid to provide 1L/h for 24 to 48 hours</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment:</strong> Dipstick urine tests to monitor urine, graduated container to monitor urine output, tourniquets</td>
<td></td>
</tr>
<tr>
<td><strong>Medications:</strong> hyperkalemia: calcium gluconate (5 x 10mL vial or Bristojet), insulin: 1 vial Humulin R (500 units), D50 (120mL)</td>
<td></td>
</tr>
<tr>
<td><strong>Pain medications</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Antibiotics</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Monitoring:</strong> 15-minute to hourly vital signs, examination, urine output documented on flowsheet</td>
<td></td>
</tr>
</tbody>
</table>

**Communications:** telephone, possibly e-mail telemedicine consultation

<table>
<thead>
<tr>
<th>Minimum</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fluids:</strong> IV fluid for initial bolus resuscitation (2L), then oral or rectal fluid resuscitation with commercial or improvised electrolyte solution</td>
<td></td>
</tr>
<tr>
<td><strong>Equipment:</strong> Graduated container to monitor urine output, tourniquets</td>
<td></td>
</tr>
<tr>
<td><strong>Medications:</strong> hyperkalemia: calcium gluconate (5 x 10mL vial or Bristojet)</td>
<td></td>
</tr>
<tr>
<td><strong>Pain medications</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Antibiotics</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Monitoring:</strong> 15-minute to hourly vital signs, examination, urine output documented on flowsheet or other written format</td>
<td></td>
</tr>
</tbody>
</table>

**Communications:** telemedicine by telephone
## APPENDIX B: CRUSH INJURY, MONITORING AND MANAGEMENT CONSIDERATIONS

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Entrapment</th>
<th>Phase 2 Extrication</th>
<th>Phase 3 Immediately Following Extrication</th>
<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FLUIDS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best</td>
<td>IV or IO crystalloids</td>
<td>Initial bolus: 2L, continue 1L/h</td>
<td>Titrate to UOP 100–200mL/h</td>
<td>Titrate to UOP 100–200mL/h</td>
</tr>
<tr>
<td>Better</td>
<td>Oral electrolyte solution</td>
<td>Continue</td>
<td>Continue</td>
<td>Continue. Goal UOP 100–200mL/h</td>
</tr>
<tr>
<td>Minimum</td>
<td>Rectal electrolyte solution</td>
<td>Continue</td>
<td>Continue</td>
<td>Continue. Goal UOP 100–200mL/h</td>
</tr>
</tbody>
</table>

**Telemedicine:** Consult on management

**Monitoring:** 15-minute to hourly vital signs, examination, urine output documented on flowsheet

### VITAL SIGNS

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Entrapment</th>
<th>Phase 2 Extrication</th>
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<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>UOP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best</td>
<td>Place Foley catheter</td>
<td>N/A</td>
<td>Record UOP every 1 hour</td>
<td>Record UOP every 1 hour</td>
</tr>
<tr>
<td>Minimum</td>
<td>Capture urine in premade or improvised graduated cylinder</td>
<td>N/A</td>
<td>Record every 1 hour</td>
<td>Record UOP every 2 hours</td>
</tr>
</tbody>
</table>

**Urine myoglobinuria**

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Entrapment</th>
<th>Phase 2 Extrication</th>
<th>Phase 3 Immediately Following Extrication</th>
<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>Laboratory monitoring</td>
<td>N/A</td>
<td>N/A</td>
<td>Every 6 hours</td>
</tr>
<tr>
<td>Better</td>
<td>Assess urine color (red, brown, or even black)</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Minimum</td>
<td>Dark urine (red, brown, or even black)</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
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</tbody>
</table>

**Potassium and cardiac arrhythmia**

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Entrapment</th>
<th>Phase 2 Extrication</th>
<th>Phase 3 Immediately Following Extrication</th>
<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best</td>
<td>Laboratory monitoring of potassium levels</td>
<td>N/A</td>
<td>Check</td>
<td>Every 4-6 hours</td>
</tr>
<tr>
<td></td>
<td>12-lead ECG</td>
<td>N/A</td>
<td>Check</td>
<td>Every 4-6 hours</td>
</tr>
<tr>
<td>Better</td>
<td>Laboratory monitoring of potassium levels</td>
<td>N/A</td>
<td>Check</td>
<td>Every 4-6 hours</td>
</tr>
<tr>
<td></td>
<td>3–5 lead ECG</td>
<td>N/A</td>
<td>Check</td>
<td>Every 4-6 hours</td>
</tr>
<tr>
<td>Minimum</td>
<td>Close monitoring of vitals and circulatory examination</td>
<td>Initiate</td>
<td>Continue</td>
<td>Continue</td>
</tr>
</tbody>
</table>

**Treatments for Hyperkalemia (>5.5mEq/L) or Cardiac Arrhythmia**

<table>
<thead>
<tr>
<th></th>
<th>Phase 1 Entrapment</th>
<th>Phase 2 Extrication</th>
<th>Phase 3 Immediately Following Extrication</th>
<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium gluconate (10%)</td>
<td>Best</td>
<td>10mL IV over 2–3 minutes</td>
<td>N/A</td>
<td>Monitor; repeat as required</td>
</tr>
<tr>
<td>Insulin (regular) and D50</td>
<td>10 units IV push + 50mL D50</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Albuterol (2.5mg/3mL vial)</td>
<td>10mg (4 vials) in nebulizer</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Sodium polystyrene sulfonate (Kayexalate)</td>
<td>15–30g suspended in 50–100mL liquid, oral or rectal</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Calcium gluconate 10%</td>
<td>Better</td>
<td>10mL IV over 10 minutes</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
### Management of Crush Syndrome Under Prolonged Field Care

<table>
<thead>
<tr>
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<th>Phase 2 Extrication</th>
<th>Phase 3 Immediately Following Extrication</th>
<th>Phase 4 Prolonged Field Care</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alternate: calcium chloride 10%</td>
<td></td>
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</tr>
<tr>
<td>Insulin (regular) and D50</td>
<td>10 units IV push + 50mL D50</td>
<td>N/A</td>
<td>N/A</td>
<td>Monitor; repeat as required</td>
</tr>
<tr>
<td>Any individual or combination of above, as available</td>
<td>Minimum</td>
<td>See above</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Management of Injured Extremity

**Extremity compartment syndrome**
- **Best**
  - Clinical assessment
  - 6 Ps:
    - Pain
    - Paresthesia
    - Pallor
    - Paralysis
    - Poikilothermia
    - Pulselessness
  - Rigid compartment
- **Minimum**

**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**

**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
    - 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.