Rhabdomyolysis Following a Gunshot Wound and One Trauma Center’s Protocol and Guidelines

In early November, a father-son hunting trip turned to misfortune. The 16-year-old boy, mistaken for a deer, was shot by his father with a .50 caliber black powder hunting rifle. Because the incident occurred in a remote area, there was an extended delay prior to initiating the 911 call. An ambulance was dispatched for transport to the nearest level I trauma center. However, because of hemodynamic instability, the patient was rerouted to a local community hospital, where he underwent immediate surgical evaluation and exploration approximately 4 hours after the initial event. The bullet had entered his right medial thigh, obliterating both the superficial femoral and profunda arteries, before exiting near the ischial tuberosity. Shrapnel remained in the bullet’s path, and significant muscle damage was noted. In the operating room, the wound was irrigated and the torn femoral artery was isolated and grafted. A fasciotomy of the right thigh was performed for relief of compartment syndrome. Once stabilized, the boy was transferred by ground to a level I trauma center 90 miles away, arriving nearly 16 hours after the injury occurred.

In the trauma center emergency department, the patient was alert and oriented. His neurologic assessment was remarkable for decreased sensation and motor function below the bullet entrance site. Deficits included an inability to fully rotate the affected extremity internally or externally. The boy also was unable to flex or extend his foot or knee, and the right patellar reflex was absent. Despite the fasciotomy, his right thigh remained tense to palpation and his dorsalis pedis pulse was absent.

Initial blood studies were significant for the following findings: creatine kinase (CK), 69,000 IU/L (45–260);...
potassium, 5.8 mEq/dL (3.5–5.1); sodium, 129 mEq/dL (136–145); phosphate, 5.7 mg/dL (2.4–4.7); and calcium, 6.8 mg/dL (8.5–10.5). Although the sending facility reported that the patient’s urine was “clear,” by the time he arrived at the trauma center, the child’s urine had darkened to tea colored, its specific gravity climbed to 1.030 (1.002–1.028), and his output was approximately 25 mL per hour.

We diagnosed the patient with rhabdomyolysis and compartment syndrome of his right leg and promptly initiated our facility’s rhabdomyolysis algorithm and protocol (Figures 1 and 2). Emergency care included aggressive fluid administration, correction of metabolic imbalances, and frequent monitoring.

Although treated with vigorous volume expansion and alkaline diuresis in the emergency department, acute renal failure developed in our patient 2 days after admission, and his creatine kinase level peaked at 89,800 IU/L. After a week of intensive medical therapy and multiple surgeries, the boy regained moderate range of motion in his right leg. Fortunately, he suffered no permanent renal damage and was discharged home in good condition approximately 1 month after admission.

Rhabdomyolysis syndrome

The cause of rhabdomyolysis is usually multifactorial. This patient’s extensive muscle damage, delay to volume resuscitation, and compartment syndrome all were risk factors that contributed to the development of rhabdomyolysis.

The syndrome of rhabdomyolysis occurs when a large number of skeletal muscle cells are destroyed. This acute muscle damage results from a variety of etiologies, most commonly severe crush injuries, ischemic compression, hyperthermia, or drug toxicities. Rhabdomyolysis following penetrating trauma is much less common and rarely has been reported in the literature.

When damaged, myocytes unleash lactic acid, myoglobin, purines, potassium, and phosphate into the extracellular fluid. Many of these muscle breakdown products are highly nephrotoxic. Conversely, massive amounts of sodium, calcium, and extracellular fluid are quickly transported into injured myocytes, contributing to hypocalcemia and hypovolemic shock. The enormous quantity of potassium released into the circulation can cause significant hyperkalemia. This, combined with uremic acidosis and an increase in lactic acid production, produces alterations in acid-base balance, which can lead to cardiac dysrhythmias as well as respiratory and neurologic complications.

Early detection of rhabdomyolysis, which is commonly first recognized by the presence of discolored urine, is important to prevent the potential complication of acute renal failure.

THE SIGNIFICANCE OF CK

When muscles are damaged, CK, also referred to as creatine phosphokinase, seeps from the cells. CK is an enzyme found in large quantities in the myocytes. This harmless enzyme serves as an excellent clinical marker reflecting the extent of muscle destruction. Normal plasma CK values are very low, only 45 to 260 IU/L. Whereas the exact level that defines rhabdomyolysis is widely debated (severe CK elevations are considered pathognomonic for rhabdomyolysis), no other condition will cause such profound elevations. Various authors have defined rhabdomyolysis as CK values ranging from 500 to 75,000 IU/L, but treatment rarely is initiated for a CK less than 10,000 IU/L. Levels start to climb minutes to hours after injury and generally peak at 24 to 48 hours. However, a patient’s prognosis following rhabdomyolysis is far more related to the timing and aggressiveness of care than it is to the extent of CK elevation.

MYOGLOBINURIA

The pink, amber, or tea-colored urine characteristic of rhabdomyolysis is produced when myoglobin escapes from injured skeletal muscles and is filtered out in the kidneys. Both hemoglobin and myoglobin cause a positive urine dipstick reaction for blood, but in the patient with rhabdomyolysis, microscopic examination will reveal few or no red blood cells.

ACUTE RENAL FAILURE

The cause of acute renal failure in patients with rhabdomyolysis is multifactorial. Initially, hypovolemia (caused by the movement of plasma fluid into damaged cells) impairs renal perfusion, slows glomerular filtration, and leads to prerenal failure. Myoglobin, a thick protein, then precipitates in the glomerular filtrate, plugging renal
Trauma Service: Rhabdomyolysis Algorithm
This is a guideline only and not to be substituted for individual clinical judgment.

OBTAIN SERUM CPK

Obtain CPK every 8 hours until 3 consecutive values decline

⇒ No

⇒ Yes

> 20,000

1) 20% Mannitol bolus: 0.5 gm/kg
2) 1000 mL DS 0.22% NaCl + 100 mEq NaHCO3
3) Begin 20% Mannitol at 0.1 gm/kg/hr
4) Begin 0.22% NaCl + 100 mEq NaHCO3 2.5 mL/kg/hr

MONITOR URINE OUTPUT HourLY

Bolus with Mannitol 0.5 gm/kg

⇒ No

⇒ Yes

> 200 mL/hr

Maintain Mannitol/ NaHCO3 infusion

Reduce Mannitol and Saline by 50% if urine output maintained > 250 mL/hr ± 2 hours

< 6

Bolus with 50 mEq NaHCO3
Recheck urine pH after 2 hours
If pH < 6.0 DO NOT BOLUS with NaHCO3

MONITOR URINE pH EVERY 4 HOURS

6-7

STOP NaHCO3 Use DS 0.45% NaCl only

VBG or ABG daily while on NaHCO3

Monitor ABG pH

⇒ No

⇒ Yes

Serum pH > 7.5

50 mEq NaHCO3 Bolus

CONTINUE TREATMENT

⇒ No

⇒ Yes

CPK < 20,000

STOP TREATMENT

FIGURE 1
Oregon Health Sciences University rhabdomyolysis algorithm. Reprinted with permission.
## Trauma Service: Rhabdomyolysis Protocol

**Primary Goal:** Maintain adequate renal status and avoid renal failure.

### Treatment Goals:
- Urine output at 200 mL/hour
- Urine pH between 6 - 7
- Serum pH above 7.50
- Hemodynamic stability

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<td><strong>Obtain Serum CPK</strong></td>
<td>If CPK above 20,000 U/L, treat</td>
<td>In a study conducted by Slater (1997), patients with CPK levels below 20,000 were not found to be at high risk for renal failure, thus the threshold for treatment changed at OHSU in March 1996.</td>
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<td><strong>Alkalization of the Urine</strong></td>
<td>1000 mL 0.22% NaCl + 100 mEq HCO3, Bolus, then run at 2-5 mL/kg/hr</td>
<td>Alkalization of the urine is advocated as helpful in minimizing renal damage following rhabdo. Patients with massive crush injuries often become acidic which results in an acidic urine. Without supplemental administration of bicarb, patients may be at risk for tubular cast development and renal injury.</td>
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<td><strong>Mannitol Diuresis</strong></td>
<td>20% Mannitol Bolus (0.5 gm/kg) Continue at 0.1 gm/kg/hr</td>
<td>Osmotic diuretic to prevent renal failure. Mannitol does not acidify the urine as do loop diuretics and has a rapid onset of action. Mannitol reduces blood viscosity and is a renal vasodilator which increases renal blood flow and increases GFR.</td>
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<td><strong>Crystalloid Infusion</strong></td>
<td>1000 mL 0.22% NaCl + 100 mEq HCO3, to run at 2 - 5 mL/kg/hr and generate a urine output of 200 mL/hr.</td>
<td>Large volumes of crystalloid are used to dilute the myoglobin load delivered to the kidneys and maintain adequate intravascular volume. This strategy reduces cast formation in the proximal tubules and &quot;flushes&quot; myoglobin out of the renal tubules. Restoration and maintenance of normal intravascular volume reduces the risk of renal failure.</td>
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<td><strong>Fluid Overload</strong></td>
<td>Consider Invasive Hemodynamic Monitoring in patients with heart disease.</td>
<td>Patients with poor myocardial contractility are at risk for volume overload and require close observation during the initial treatment for Rhabdomyolysis. Evidence of fluid overload such as infiltrates via CXR and elevated CVP are indicators for invasive hemodynamic monitoring.</td>
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<td><strong>Acute Renal Failure</strong></td>
<td>Oliguria requires conversion to a diuresis within one to two hours to avoid ARF.</td>
<td>Despite optimal treatment, patients can develop renal failure, especially if treatment begins in the later development phases of Rhabdo. Early initiation of high output diuresis is essential in the prevention of acute renal failure. Consider patient to be in Acute Renal Failure and stop treatment if patient fails to diurese after two hours of treatment.</td>
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*FIGURE 2
Oregon Health Sciences University rhabdomyolysis protocol. Reprinted with permission.*
tubules and causing brown cast formation. In an acidic environment, myoglobin dissociates and releases a free iron complex that is directly toxic to the cells of the renal tubules. Because of the significant role myoglobin plays in this syndrome, rhabdomyolysis often is referred to simply as myoglobinuric renal failure.

Assessment

Initial signs and symptoms of rhabdomyolysis are nonspecific and include musculoskeletal pain, weakness, decreased deep tendon reflexes, flaccid paralysis of the injured limb, dark urine, and falling urine output. Laboratory values suggestive of the condition include elevated CK, potassium, and phosphate levels, a urine specific gravity greater than 1.025, and a drop in serum calcium.

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Emergent interventions

Muscle tissue is highly resilient and generally heals effectively over time. Therefore, the primary goal of rhabdomyolysis therapy is the prevention of hypovolemia, life-threatening dysrhythmias, and renal dysfunction. Treatment includes careful assessment, intravenous volume replacement, alkaline diuresis, correction of electrolyte imbalances, and cardiac monitoring.

FLUID REPLACEMENT

Prompt initiation of intravascular volume replacement is the single most important defense against the complications of rhabdomyolysis. Fluid replacement with large volumes of intravenous crystalloids prevents cardiovascular collapse, restores normovolemia, reduces acidosis, flushes nephrotoxic debris from the renal tubules, and minimizes hyperkalemia. There is no consensus in the medical literature on the optimal rate of fluid administration. Infusion rates of 200 to 700 mL per hour have been proposed. Most researchers advocate titrating the rate of crystalloid administration to maintain a urinary output of at least 100 to 200 mL per hour, with a low specific gravity.

When conventional therapies fail, hemodialysis or continuous renal replacement therapy are used to support renal function. Indications for emergent dialysis include an inability to maintain an adequate urine output, continued hyperkalemia, persistent metabolic acidosis, severe pulmonary edema, and congestive heart failure. In the patient with rhabdomyolysis, the need for dialysis is almost always short term.

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DRUG THERAPY

As the muscle cells release potassium, lactic acid, and other organic acids, metabolic acidosis ensues and urine pH drops. At a urine pH less than 6, myoglobin dissociates into a nephrotoxic iron compound. Alkaline diuresis therapy prevents the development of acute renal failure by inhibiting this event. Sodium bicarbonate (40 to 100 mEq added to each liter of fluid) lowers the pH of the filtrate in the proximal tubules. Because of the large amount of sodium contained in sodium bicarbonate, this drug is generally added to a 5% dextrose and 0.45% saline solution or 5% dextrose and 0.22% saline solution instead of 0.9% saline solution. Unfortunately, sodium bicarbonate can aggravate hypocalcemia by promoting calcium deposition in injured myocytes. Mannitol administration serves to protect both damaged muscles and the kidneys. By raising pressure in the renal tubules, mannitol increases flow and flushes out toxic myoglobin plugs. Loop diuretics are occasionally given as an adjuvant therapy for the treatment of rhabdomyolysis, though these drugs can acidify the urine. Adequate fluid resuscitation is necessary with concurrent mannitol administration.
CORRECTING ELECTROLYTE IMBALANCES
Rhabdomyolysis is associated with significant electrolyte disturbances. Emergently, symptomatic hyperkalemia is treated with intravenous glucose and insulin to drive extracellular potassium back into the cells. In the initial stages of rhabdomyolysis, calcium levels are commonly low as a result of an intracellular calcium shift. Replacement therapy for hypocalcemia generally is not recommended because of the potential for increasing intracellular calcium deposition. As rhabdomyolysis resolves, calcium levels will self-correct.

Alkaline diuresis therapy prevents the development of acute renal failure by inhibiting this event [ie, the dissociation of myoglobin] into a nephrotoxic iro compound.

PATIENT MONITORING
Because of their aggressive fluid management needs, nursing care of this population includes strict intake and output measurement. Continuous pulse oximetry and frequent respiratory assessment are essential to monitor for fluid overload, particularly in elderly patients. Cardiac disturbances from electrolyte imbalances, most notably hyperkalemia, require careful monitoring, especially during the early postinjury phase. Nurses should watch for ventricular ectopy, peaked T waves, and prolonged PR intervals. Coagulation studies are also indicated because large amounts of tissue factor are released from injured muscle cells, promoting clotting disorders.

REFERENCES