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Crush Injury During Winter in the Backcountry: A Case Report

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Abstract

Crush injuries are complicated and uncommon in prehospital medicine. They combine the complications of traumatic injuries, medical syndromes, and technical rescue. This conflagration of complex management issues can be very difficult for prehospital providers to control. Managing a crush injury in an austere environment adds a much higher degree of complication. In this article we present the case of an adult male who sustained a right leg injury when a boulder pinned his leg on a trail in Eldorado Springs Canyon, Colorado during a winter storm with subfreezing temperatures. Remote location and a harsh environment added to the complexity of this already difficult patient injury. A positive outcome was achieved by early recognition of the potential for crush syndrome by the treating medics, a coordinated lift operation with rescue crews, and a prompt field evacuation via litter.

Introduction

Crush injuries and crush syndrome are often seen in the urban environment related to building collapse. One of the first descriptions of Crush Syndrome came from Dr. Eric Bywaters during the Blitz in World War 2 London (Peiris, 2016).

Crush injuries occur when tissue is compressed, reducing circulation to tissue that is distal to the injury, and causing cell lysis. There are many mechanisms that can cause crush injuries, examples of which include climbing harness misuse or heavy object impingement. Crush Syndrome is a subset of crush injuries in which skeletal muscle is damaged by a blunt force, leading to metabolic changes and release of intracellular contents (Rajagopalan, 2011). Altered mental status in patients with moderate hypothermia has been documented. In this case, the responders reported symptoms of altered mental status among responders due to worsening hypothermia. Weather on the date of the call was a high of 28 deg F (-2 deg C) with 15 MPH (24 km/h) winds out of the Northeast.

Case Report

We report on the case of a 23-year-old male who sustained a crush injury when his foot became trapped under a several ton granite boulder that dislodged and trapped him while hiking.

The injury occurred on a cold December day late in the afternoon, approximately 2 miles (3.2 km) up a mountain trail located in a boulder scree field. The patient required an extensive extrication operation to remove the boulder pinning him, as well as an extended wheel out via litter to the nearest road for evacuation to a trauma center.

Initial dispatch occurred at approximately 1330 with information that a male who was hiking in Eldorado Canyon state park had a large boulder dislodge onto him and his leg was pinned underneath. An ALS ambulance equipped with back country rescue gear, an ALS fire engine, a fully stocked high angle/back country rescue company, and a local Search and Rescue team were initially dispatched.

Initial responding crews hiked up the steep trail approximately 2 miles (3.2 km), which lead them to a steep scree field of granite boulders where the patient was about 500 feet above the trail.

Upon arrival at the patient, he was laying on a large boulder with his lower right leg from the ankle down pinned between two large granite boulders. The larger boulder had become dislodged and rolled onto the patient when he attempted to use it to pull himself up onto it. The boulder was unstable and resting on its lateral edge and needed to be secured by anchoring it to a nearby tree with rope and a back tensioned tie off. The patient had been pinned for about 90 minutes prior to responder arrival and was screaming loudly in pain. He denied any medical history, current medications, or medical allergies.

A rapid trauma exam was performed. The right lower leg from the ankle down was compressed under the rock, but the rest of the full body exam was unremarkable. No obvious hemorrhage was noted. The patient stated he was in a lot of pain and that he could not feel his foot. He also stated he was nauseous and extremely cold. He was alert and denied any other complaints or injuries.

Due to the extreme cold (28° F, -2°C) and working in a steep and icy scree field, the patient's vitals were monitored by finger pulse-ox, maintenance of a radial pulse, and constant verbal communication. An intravenous line (IV) was established and the patient was given 4mg of ondansetron (Zofran) and 30mg of ketamine (Ketalar), which relieved some of the pain and reduced his nausea. Due to the cold temperatures, IV fluids were warmed by wrapping the IV tubing around hot packs to keep the patient from becoming too hypothermic. This provided some relief to the patient's shivering and he noted that he felt “a little warmer.” In addition, thermal blankets were wrapped around the patient. Ultimately the medic ended up hugging him to maintain his warmth.

Pain management with ketamine (Ketalar) and warm fluids were continued while additional crews arrived on scene and worked on boulder removal. A set of lift bags that fill with air to lift objects were brought up as well as air bottles for filling. In addition, two sets of mechanical advantages were established to aid in the lift and to capture any progress made with a load releasable system. One of the systems relied on a cable and mechanical crank system similar to those found on a boat. The second system was a 9 to 1 mechanical advantage using 11mm rope and pulleys.

By the time the rigging for lift operations had been completed, the patient had been pinned for approximately 3 hours. The decision was made to implement the crush syndrome protocol and to coordinate with the lift team on when to move the boulder.

Prior to movement of the boulder the patient was given 7.5 mg of Albuterol via nebulizer, 100 meq of sodium bicarbonate, 1 mg of calcium chloride, and 1 litre of normal saline. Immediately before the boulder was removed, an additional dose 30 mg of ketamine (Ketalar) was given for pain.

The boulder was then lifted approximately 5 inches (12 cm) and the patient was pulled free onto a waiting full body vacuum mattress and warming blankets. The patient was secured into the vacuum mattress and placed in a mobile litter for evac. The lower leg was examined and had no obvious hemorrhage or gross deformity. The patient was wearing a running sneaker with 3 layers of socks. Due to the extended time it would take to evac the patient combined with the colder weather, the shoe was kept in place with the shoelaces cut to allow for potential swelling. The patient was alert and oriented and had no change in condition post removal of the boulder.

The temperature had dropped to 12° F (-11°C) and the wind had picked up by this point, causing the patent IV line and fluids to freeze, despite having improvised warming devices. All further medications were given intramuscular to overcome this complication.

The carry out with the litter took approximately 90 minutes, during which time the patient was given 3 more doses of ketamine (Ketalar), given intramuscular since the IV had been lost, and another dose of ondansetron (Zofran). The patient remained stable and was able to carry on a conversation throughout the evacuation.

Upon arrival at the ambulance the patient was wrapped in warm blankets and moved onto the stretcher. The shoe was removed to find minor deformity to the lateral aspect of the foot. Severe swelling of the entire foot was noted, there were no palpable pedal pulses, and the toes appeared dusky and had poor capillary refill. The patient was placed on the cardiac monitor and an EKG showed sinus rhythm with no noted ectopy or ST segment elevation.

The patient was transported to the nearest trauma center 20 minutes away where he was met by the trauma team in the Emergency Department. He was admitted to the hospital where care was transferred to the trauma surgery team for surgical consultation, treatment, and ultimately, rehabilitation.

Discussion

This case presented a number of staggering complications for the responders. First, the pathology of crush injuries places patients with those injuries at high risk of decompensation. Second, the complex nature of removing the patient from the entrapment, and then extricating the patient from the environment. Third, the environment itself was distant from resources on a day with below freezing temperatures, leading to hypothermic conditions that impacted not only the patient but the providers as well.

Pathophysiology of Crush Injuries

The complexity of crush injuries is often discussed in relation to mass casualty large scale events, such as earthquakes. In this case study there was only a single patient to be managed, but the patient had been injured a significant distance from definitive care resources. The cells in the patient's leg were crushed by the weight of the boulder, causing immediate lysis of some of the cells and ischemia of others. The initial insult from the boulder falling on the patient’s leg caused traumatic rhabdomyolysis.

Traumatic rhabdomyolysis occurs when there is compression of the skeletal muscle (Sever, 2011). When skeletal muscle is compressed there is an increase in permeability of the sarcolemma. This increase in permeability causes a shift of ions between the extracellular space and the intracellular space of the sarcolemma. The shift in ionic concentrations results in a high extracellular concentration of potassium and a high intracellular concentration of calcium. The increase in extracellular potassium can cause cardiac arrhythmias. The decrease in extracellular calcium results in muscle spasms, which cause depletion of the adenosine triphosphate (ATP). This is exacerbated by compromised ATP production in the case of compartment syndrome due to the anaerobic nature of the ischemic cells (Lovallo, 2012). Traumatic rhabdomyolysis left untreated, and sometimes in spite of treatment, can progress to acute kidney injury and multi-organ failure. Reperfusion of the entrapped tissue causes oxygen free radical generation, which attracts neutrophils and releases enzymes that kill more cells. The sudden massive cellular death causes fluid dysregulation and localized edema. Fluid shifting from the cells and vascular space into the interstitial space causes worsening of compartment syndrome and can even cause hypovolemic shock.

Treatment of Crush Injuries

Treatment for crush injuries can be complicated due to the involvement of multiple organs and systems. As with all traumatic injuries, it is important to discern the mechanism and severity of injury to be sure that the injury is not a distraction from other life threats. Clinicians should be cognizant of the potential for compartment syndrome as a differential diagnosis in those who suffer a crush injury. Compartment syndrome can be discerned from a crush injury using the metrics of pain, pallor, paresthesia, paralysis, poikilothermia and pulselessness commonly referred to as the six P's (Sever, 2011). Findings can be one or multiple of the six P's and should be observed for signs of worsening compartment syndrome.

Treatment of crush syndrome should focus on mitigating the effects of traumatic rhabdomyolysis to prevent acute kidney injury. Fluid boluses should be administered before and after releasing the entrapped tissue to lessen the effect of shifting ionic gradients. Early aggressive fluid replacement has been shown to positively improve patient outcomes by avoiding acute renal failure (Sagheb, 2008). The temperature of the environment should be noted to discern if the affected tissue is poikilothermic. Albuterol can be administered by nebulizer, if there are no contraindications present, to mitigate the hyperkalemia associated with traumatic rhabdomyolysis. Sodium bicarbonate is recommended in crush injuries to curb the effects of lactic acidosis and hyperkalemia (Sever, 2011). Calcium can be administered if the patient has a severe hypocalcemia but should be used sparingly to avoid hypercalcemia. Calcium can be deposited in injured tissue and then resuspended once the injury is treated, causing an acute hypercalcemia (Sagheb, 2008). Though not frequently carried in the prehospital environment, insulin and D50 would also be appropriate for administration in these patients to reduce the elevated potassium levels. Mannitol is used by some services in the treatment of crush injuries; however, its use can be dangerous when used in higher doses, causing renal vasoconstriction and worsening hyperkalemia (Better, 1997).

Environmental Challenges

Some of the responders from the presented case reported shivering, feeling mildly altered and lightheaded after spending time on the scene. On the day of the rescue, the temperature was 28° F (-2°C) with a wind speed of 15 mph (24 kph). The temperature was bearable for hiking in a light jacket, but when responders arrived at the patient they were sweating and losing heat quickly. Research has shown that hypothermia is easily avoided with moderate activity, but after cessation of activity in a cold climate heat is lost rapidly (Procter, 2018). Intermittent activity causes the body to use more O_2 and more glucose for thermoregulation (Weller, 1997). The effects of mild hypothermia on responders can seem small but can greatly complicate an already complicated rescue. Shivering is the involuntary process by which the body attempts to increase the rate of heat production. For responders, shivering comes at the cost of loss of dexterity and accelerated energy use. Simple tasks like starting IVs and tying knots become major obstacles when shivering. Responders who reported shivering and mild hypothermia were predominantly wearing a cotton sweater. Research has shown that a windbreaker jacket and light polyester cap are effective for avoiding hypothermia during times of intermittent physical activity (Burtscher, 2012). Responding in an environment like the case presented is also a challenge for the medical equipment and medications used. Medications are formulated to be stored and administered at temperatures within a narrow range to achieve the expected outcome. The freezing point of normal saline is similar to water, 0° C. On the day of the presented case, the temperature was below the freezing point of saline. The saline in the IV administration set was at risk of freezing. To mitigate the freezing of saline problem, a heat pack was wrapped around the lines and taped in place. This heated the saline at a point proximal to the patient to avoid flow problems with the IV and also to avoid causing hypothermia in the patient.

Ketamine for Pain

Ketamine has been shown to be an effective standalone treatment for pain management in trauma patients (Yousefifard, 2019). Ketamine works as an N-methyl-d-aspartate (NMDA) receptor antagonist which is known for its analgesic properties at low doses (Jabourian,2020). Doses above 1 mg/kg of ketamine are used for anesthesia in both an induction and perioperative role. Doses of 0.3 mg/kg are increasing in use for pain management in the emergency department and prehospital settings. This lower dose of ketamine has been shown to increase nitric oxide synthesis (Romero, 2011) while binding to the μ opiate receptor. The result of this lower dose is an inhibition of nociception. This can be even more effective when paired with an opiate medication, like morphine, due to the synergistic relationship the medications have on opiate receptor sites (Lee, 2016).

There are advantages and disadvantages to using ketamine for pain management. Patients are less likely to form a tolerance for ketamine. With opiate usage and overdoses at pandemic levels in the United States, many providers are looking for alternative medications to administer for pain management. Studies have even shown that ketamine can help in the cessation of opioid abuse (Jabourian, 2020). Another advantage to ketamine is that is has very little effect on the circulatory system. When compared to opiates, ketamine has much lower risk of cardiovascular and respiratory complications (Lee, 2016). Patients that were administered low dose ketamine for pain often have a small increase in blood pressure, whereas opiates are known to cause a decrease in blood pressure (Jabourian, 2020). This makes ketamine an ideal drug for trauma patients, especially those who are in austere environments farther away from definitive care. Ketamine has been found to have neuropsychiatric side effects, such as hallucinations and nausea, even at low doses. These side effects could greatly complicate a back-country rescue, as they could turn a compliant patient into an aggressive combatant. Neuropsychiatric side effects of ketamine have been found to be mitigated by slow infusion of 2-3 µg/kg/minute in low concentrations (Lee, 2016).

Extrication Challenges

The remote location and limited prearrival information provided to the initial responders meant that equipment normally reserved for auto extrications had to be carried manually into the remote location. This included lifting air bags, air bottles, wedges, and the additional ropes, cables, and lifting pulleys. The amount of equipment and its added weight meant a significant delay in time from arrival at the base of the canyon until the equipment and personnel could make it to the scene.

Once in place, the lifting bags added another unforeseen challenge. As the boulder was being lifted, it rotated on its axis, rather than rising vertically. The initial operation had to be paused while an additional mechanical advantage system was built using cables and a winch to stabilize the lateral movement and ensure a safe lift for all crews involved.

After removal of the patient, he was placed into a litter and had to be continually monitored by medics, while at the same time be wrapped in warming blankets to maintain body heat. Additionally, the steep incline of the scree field, approaching darkness, and complicated route out increased the complexity of the carry. Walking belays were established at approximately 100-foot (33 m) intervals to act as a backup should a rescuer lose their footing, thus preventing a runaway litter type event.

Air evacuation by helicopter was not possible due to the high winds and snow that had increased throughout the duration of the rescue.

Conclusion

Crush syndrome management can be difficult even in the best of circumstances. Providing appropriate care and coordination on a complex operation can be overwhelming for initial responders. The presented case report details the challenges met by responders that included a pinned party, harsh environment, extrication, medical management, and ultimate evacuation to a trauma facility. Lessons learned from this event include the need for long term warming methods for responders, patients, and medications as well as providing the responders with the abstract training opportunities that allow for onsite problem solving. Through a coordinated effort involving multiple agencies a positive outcome for this patient was achieved.

Works Cited

Better, O. S., Rubinstein, I., Winaver, J. M., & Knochel, J. P. (1997). Mannitol therapy revisited (1940-1997). Kidney international, 52(4), 886–894. https://doi.org/10.1038/ki.1997.409

Burtscher M, Kofler P, Gatterer H, Faulhaber M, Philippe M, Fischer K, Walther R, Herten A. Effects of lightweight outdoor clothing on the prevention of hypothermia during low-intensity exercise in the cold. Clin J Sport Med. 2012 Nov;22(6):505-7. doi:10.1097/JSM.0b013e318257c9cc. PMID: 22584959.

Dissociative Dose of Ketamine in the Treatment of Trauma-Related Pain in Adult Civilian Population. Cureus, 12(8), e9567. https://doi.org/10.7759/cureus.9567

Jabourian, A., Dong, F., Mackey, K., Vaezazizi, R., Pennington, T. W., & Neeki, M. (2020). Evaluation of Safety and Efficacy of Prehospital Paramedic Administration of Sub-
Lee EN, Lee JH (2016) The Effects of Low-Dose Ketamine on Acute Pain in an Emergency Setting: A Systematic Review and Meta-Analysis. PLOS ONE 11(10): e0165461. https://doi.org/10.1371/journal.pone.0165461

Lovallo, E., Koyfman, A., & Foran, M. (2012, July 20). Crush syndrome. Retrieved September 21, 2020, from https://www.sciencedirect.com/science/article/pii/S2211419X12000675?via=ihub

Peiris D. A historical perspective on crush syndrome: the clinical application of its pathogenesis, established by the study of wartime crush injuries. J Clin Pathol. 2017;70(4):277-281. doi:10.1136/jclinpath-2016-203984

Procter, Emily, et al. "Accidental Hypothermia in Recreational Activities in the Mountains: A Narrative Review." Wiley Online Library, John Wiley & Sons, Ltd, 1 Oct. 2018, onlinelibrary.wiley.com/doi/full/10.1111/sms.13294.

Rajagopalan, S. (2011, July 21). Crush Injuries and the Crush Syndrome. Retrieved September 13, 2020, from https://www.sciencedirect.com/science/article/abs/pii/S0377123710800073?via=ihub

Romero, Thiago R. L., MD; Galdino, Giovane S., MD; Silva, Grazielle C., MD; Resende, Lívia C., MD; Perez, Andréa C., PhD; Côrtes, Steyner F., PhD; Duarte, Igor D. G., PhD Ketamine Activates the l-Arginine/Nitric Oxide/Cyclic Guanosine Monophosphate Pathway to Induce Peripheral Antinociception in Rats, Anesthesia & Analgesia: November 2011 - Volume 113 - Issue 5 - p 1254-1259 doi: 10.1213/ANE.0b013e3182285dda

Sagheb, M. M., Sharifian, M., Roozbeh, J., Moini, M., Gholami, K., & Sadeghi, H. (2008). Effect of fluid therapy on prevention of acute renal failure in Bam earthquake crush victims. Renal failure, 30(9), 831–835. https://doi.org/10.1080/08860220802353785

Sever, M. S., & Vanholder, R. (2011). Management of crush syndrome casualties after disasters. Rambam Maimonides medical journal, 2(2), e0039. https://doi.org/10.5041/RMMJ.10039

Weller AS, Millard CE, Stroud MA, Greenhaff PL, Macdonald IA. Physiological responses to cold stress during prolonged intermittent low- and high-intensity walking. Am J Physiol. 1997 Jun;272(6 Pt 2): R2025-33. doi: 10.1152/ajpregu.1997.272.6.R2025. PMID: 9227624.

Yousefifard, M., Askarian-Amiri, S., Rafiei Alavi, S. N., Sadeghi, M., Saberian, P., Baratloo, A. & Talebian, M. T. (2019). The Efficacy of Ketamine Administration in Prehospital Pain Management of Trauma Patients; a Systematic Review and Meta-Analysis. Archives of academic emergency medicine, 8(1), e1.