Emily Humphreys

The SCIence of Treating Spinal Cord Injuries in a Backwoods Setting

This paper weighs the potential risks and benefits of emploing an external cooling pad to the area of the spine in the first day after spinal injury as a tool for emergency intervention in isolated areas.

Wilderness activities can be incredibly rewarding. They are a way to experience nature, practice problem solving, and stay physically fit. Still, going into a less accessible area, often many hours from a hospital, poses a risk (Bledsoe, 2008). Wilderness activities have become increasingly popular in recent years; for example, 1.4 billion more outdoor expeditions were made in 2011 than 2010, and this growth was not atypical (Recreation Report, 2012). As wilderness activities become more popular, so have fatalities associated with them (Bledsoe, 2008). A spinal cord injury, or SCI, can be particularly devastating on an expedition. Every year in the US, one in 1,000 people suffers from a SCI, with 12% of those being from falls and 24% of those being from sports (Zhu et al., 2010). Participating in ice climbing, rock climbing, and hiking, sports associated with a risk of falling from great height, would then lead to a greatly increased risk of traumatic spinal cord injury. Spinal cord injuries often cause patients to lose motor and sensory function, and can be fatal (Zhu et al., 2010: Bowes, 2014). Additionally, they can lead to drastic changes in the patient's quality of life, affecting the patient personally, economically and socially (Bowes, 2014). About half of SCIs lead to irreversible damage (Zhu et al., 2010). Because of the potential consequences, it is crucial that medical responses to SCIs be swift and through. It is estimated that somewhere between 3% and 25% of total spinal cord damage happens after the initial injury as the nervous tissue immediately surrounding the sire of trauma is extremely vulnerable; most of these secondary injuries occur in the first 12-24 hours, so early medical intervention is key (Zhu et al., 2010: Nicholas, et al., 2013). One emerging treatment option, is the application of a cooling pad to the external region near the spine (Zhu et al., 2010). I propose that a cooling pad could be a feasible and beneficial part of SCI treatment in backwoods situations. I suggest more research should be done into the potential of selective cooling in cases where access to a spinal care unit is delayed. For the purposes of this paper, a wilderness or backwoods environment shall refer to a place where active patient evacuation would take between six hours and a day to initiate and all supplies and resources available are portable enough to be carried for days at a time.

Encased within the spinal column, the spinal cord is a key part of the central nervous system (McDowell, 2004). Here, electrical impulses travel between the brain and much of the rest of the body through nerve fibers. (McDowell, 2004). The spinal cord runs from the brain down the back and in adults, measures an average 50 cm in length (Zhu et al., 2010). The center of the spinal cord features grey matter, characterized by a lack of myelination, which is surrounded by the myelinated white matter; myelination allows nerve signals to travel faster (Lin, 2003: Parker 2013). The spinal cord is protected by three layers of connective tissue called the meninges (Parker, 2013). Underneath the second layer is the cerebral spinal fluid (CSF) which protects the spinal cord and carries away waste (Zhu et al., 2010: Parker, 2013). In-between the spinal cord and the vertebrae, also exists a thick layer of fat and other connective tissue called the epidural space (Parker, 2013). The epidural space is packed with blood vessels

carrying oxygen, white blood cells, hormones and more (Parker, 2013). In addition to nervous cells, the spinal column also hosts many types of glial cells, which play a supportive role, and have wide variety of functions including insulating neurons, forming scar tissue, and releasing signaling molecules (Bowes, 2014: Lin, 2003). Astrocytes are by far the most common type of glial cell in the spinal column (Zhu et al., 2010).

When the spinal cord is injured, many changes immediately occur in the body, including biochemical, inflammatory, and vascular responses (Bowes, 2014). The body's natural, cascading immune response to SCI has the potential to both aid in stabilization and repair or act degenerately and lead to the destruction of tissue surrounding the injury (Bowes, 2014). For example, inflammatory mediators such as cytokines, help to manage debris, spur tissue repair, and protect the structural integrity of the spine (Bowes, 2014). At the same time, they can damage nerve cells and galea, leading to cell death and scarring (Lin, 2003). Swelling and excitotoxicity, a process where nerve cells are overloaded with an abundance of signaling molecules, lead to additional damage (Lin, 2003).

Cooling works by slowing internal processes, which has major effects on the spine and spinal healing. Almost all chemical reactions happen more slowly at lower temperatures, and biological processes are deeply rooted in chemical reactions (Petrucci, 2007). To slow down these processes is to suppress the rate at which the body can react to external stimuli and internal messages. In the case of SCI, this means cooling slows down the body's natural, cascading immune response. Additionally, drops in temperature activate cutaneous receptors, sensory receptors found in skin, which then stimulate sympathetic fibers to narrow blood vessels in the body's attempt to maintain homeostasis by preserving its core temperature (Cochrane, 2004). This limits blood flow in the region of the spine, and in turn limits the effect of cytokines, neutrophils, lymphocytes, and other immune agents which gain access to the spinal region via circulation in the blood (Dietrich, 2011: Nemet, 2009). The overall effect is a marked reduction in swelling, inflammation, and intracranial pressure (Cochrane, 2004 : Shann, 2003). In the case of a wilderness emergency, delaying cascading immune reaction makes sense, as it may extend critical windows to perform more complicated treatments that can only take place in a spinal care unit, such as administering immune suppressors. Additionally, clinical studies have shown that cooling reduces the rate at which spinal cells consume oxygen by slowing down cell respiration (Zhu et al., 2010). Because of the potential for tissue ischemia, lack of blood supply and crucial oxygen and glucose, after SCI, cooling further reduces secondary cell death (Zhu et al., 2010).

A recent experiment by Zhu et al. explored the possibility of inducing localized spinal cooling via an external cooling pad, in order to prevent secondary spinal injury. Previously, induced local hypothermia had been recognized for its potential to improve SCI outcomes, but had been largely restricted to surgical treatments where cooling agents were directly applied to spinal tissue. The team wanted to see whether their cooling technique, using a cooling pad placed on the back, would be able to reduce spinal cord temperatures by 3.6°F, a drop significant enough to have major effects on spinal healing. This peer reviewed study used computer simulations to model the spinal cord and surrounding tissue. Using Pennes bioheat equation, they found that a 68°F cooling pad, 50cm by 10cm, applied externally to the spinal region for 30 min could reduce the temperature of the spinal cord by 4.9 °F. While there were no human participants, the model did take into account the thermal conductivity, specific heat capacity, density, local blood perfusion rate, and local volumetric heat generation rate of spinal cord tissue,

bone, muscle, blood, and cerebrospinal fluid. The detail of this model allows the findings to hold weight, though it should be recognized that all variables were filled in with averages to which no patient would perfectly adhere (Zhu et al, 2010). While this research is still in its infancy, a more recent study on twenty human participants found that, when a cooling saddle was applied externally within the first hours after SCI, sixty percent more patients regained some apparent nervous capabilities, compared with those without cooling (Ramer et al., 2014). The cooling in this study was comparatively more intense (Ramer et al., 2014), but still serves to corroborate the general findings of Zhu's team regarding the usefulness of eternal cooling pads. I propose that this method of cooling, half hour intervals with a 68°F cooling pad, could encourage positive outcomes in backwoods cases of SCI. Because of the risk of hypothermia, I would advise treatment only in half hour intervals, as were studied here, with at least a half hour of rewarming between active cooling.

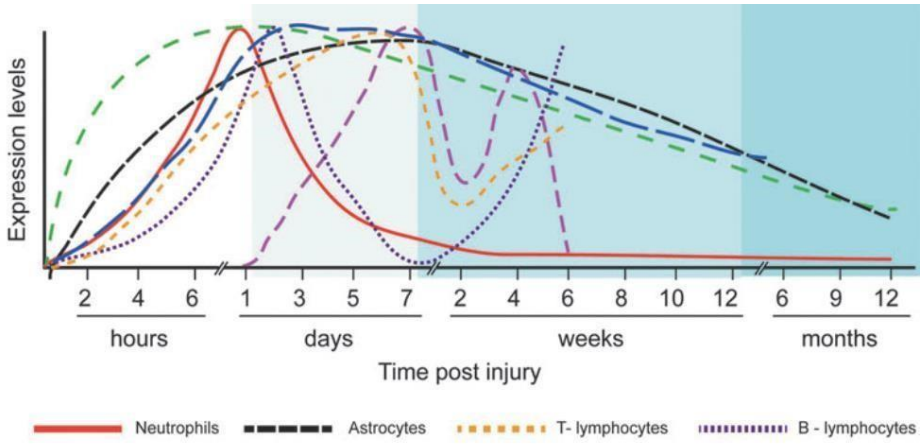

Figure 1: This graph shows the progression of the expression of various immune agents after SCI (Bowes, 2014). Note the rapid escalation of activity during the first day.

I suggest that cooling purposefully timed to align with the progression of the immune response over the first day after injury would lead to better outcomes. Immune agent activation ramps up through the first day of injury (Bowes, 2014). Agents include neutrophils, B-lymphocytes, T-lymphocytes, and astrocytes (Bowes, 2014). All of these cell types have the potential to create a type of regulatory proteins called cytokines (Lin, 2003). Many types of cytokines are released after SCI, some pro-inflammatory and some anti-inflammatory (Lin, 2003). TNF-α is a pro-inflammatory cytokine that works by increasing the permeability of cell membranes, allowing immune agents to pass through (Lin, 2003). Studies have shown that TNF-α promotes neurotoxicity and its attenuation improves outcomes (Lin, 2003). TNF-α begins being produced in large quantities approximately one hour after SCI (Lin, 2003). In order to slow the action of TNF-α, a two-hour cooling session, with two periods of active cooling, could begin forty-five minutes after injury. Neutrophils, a type of white blood cell, are also a major player in the SCI immune response (Bowes, 2014). These cells have been linked to the production of inflammatory cytokines and proteolytic enzymes, ultimately resulting in greater secondary cell death (Bowes, 2014). Studies have repeatedly shown that a reduced blood neutrophil count correlates with a reduction in secondary injury (Bowes, 2014). Neutrophil levels are highest at just under a day post-SCI (Bowes, 2014). To counteract the worst of their damage I would

recommend a session of cooling starting at 20 hours and lasing until active evacuation is begun. Additionally, cooling could be strategized to delay and repress the sharp rise in B-lymphocyte levels, seen beginning at a about five-hours post SCI and continuing for just over a day (Bowes, 2014). The activation of B-lymphocytes, a type of white blood cell, correlates highly with the synthesis of CNS antigen targeted antibodies (Bowes, 2014). These antibodies lead to significant increase in secondary injury (Bowes, 2014). I would recommend a two-hour session of cooling at five hours to slow B-lymphocyte activation. The peak in B-lymphocyte levels will also be delayed by the session starting at 20 hours. While cooling may not entirely discourage the peak in B-lymphocyte activation, it could certainly help to delay it until the patient was able to be transported to an acute spinal unit where doctors could properly monitor and respond to the progression of patient's cascading immune response.

While attempting to staunch the effects of neurotoxic immune responses, it is important to not inadvertently hinder beneficial ones. T-lymphocytes, another type of white blood cell, exhibit a biphasic response (Bowes, 2014). The first spike in T-lymphocyte levels is thought to be neuroprotective, though its mechanism is not fully understood (Bowes, 2014). T-lymphocytes gain access to cells in part because of the increased membrane permeability caused by TNF-α. In turn, they themselves synthesize TNF-α (Bowes, 2014). The suggested cooling above would seriously inhibit the action of both TNF-α and T-lymphocytes in the first hours post-SCI. Although T-lymphocyte levels are moderate during this time, they do not see their first peak until seven days after SCI, and so the negative effect of the cooling would ultimately be limited. Astrocytes, a type of glial cell, are also very important during the first day after SCI (Bowes, 2014). Upon injury, astrocytes become activated and their phenotype becomes hypertrophic, meaning they enlarge (Bowes, 2014). This builds a thick glial scar around the site of injury (Bowes, 2014). This scar is nearly impenetrable and prevents immune cell access to the site of injury, blocking potentially neurotoxic agents and guarding against secondary cell death (Bowes, 2014). Beyond this, astrocytes produce the cytokine IL-10 (Bowes, 2014). IL10 leads to a reduction in levels of harmful TNF-α (Lin, 2003). It would be unfortunate to inadvertently inhibit the neuroprotective role of astrocytes through emergency localized spinal cooling. While this is a risk, astrocytes are glial cells, which live inside the spinal region and rely less on transport through the blood (Bowes, 2014). This means that cooling would have a comparatively measured effect on the work of activated astrocytes. Another long-term consideration is that, while spinal scarring is thought to be neuroprotective, it also discourages axon regeneration, whereas unscarred, degenerating white matter is more hospitable to axon regeneration post-SCI (Lin, 2003). Because of this, any astrocyte inhibition caused by the cooling may not be wholly negative. Although there are many neuroprotective responses occurring simultaneously with neurodegenerative ones, when viewed cumulatively I suggest the potential for increased secondary injury, outweighs the benefits of the immune response in the first twenty-four hours. This is further supported by the fact that anti-inflammatory drugs are often given to SCI patients in a hospital setting during their first day of injury (Lin, 770). The cooling pad could perform a similar function in a place far away from medical facilities.

Induced localized cooling as a response to acute traumatic SCI appears to have the potential to be not only effective, but also practical. In my model, outdoor cooling would require a cooling pad that could be at warm temperatures for days and still become cool quickly and reliably; the pad would, then need to maintain a steady 68°F for up to a day. While I have found no commercial cooling pads that currently meet all those specifications, a chemical cooling pad

could be engineered for the job. Chemical cooling pads feature two reactants, separated by a thin barrier (Hinckley, 2017). They can remain at high temperatures for days at a time, and then cool quickly when the barrier is broken (Hinckley, 2017). When this happens, usually because of a vigorous shake, the reactants meet and begin endothermically reacting, meaning the reaction uses up heat (Hinckley, 2017). As a result, the cooling pad undergoes a controlled drop in temperature. A competitive inhibitor, which would help ensure the cooling lasted for twenty-four hours and moderate the degree of cooling, could also be added to the mix. The cooling pad studied by Zhu et al. was ten cm by fifty cm, and their analysis showed that reducing the width to five cm would have little impact on the effectiveness of cooling (Zhu et al., 2010). SAM splints, which are of similar size to the proposed cooling pad (about 36in by 4in), are currently regularly included in wilderness first aid kits (SAM, 2017). To add another object of this size, especially on high SCI-risk trips like rock or ice climbing, would be very feasible. Due to its small size and practical build, transporting an effective cooling pad would be no great hindrance for a group of travelers.

Importantly, I believe cooling could be safely administered by Wilderness Outdoor First Responders (WOFR) or Wilderness EMTs. These two designations require significant practical training, and almost all trips coordinated by an outdoors program have a member who has received one or both titles (Nols, EMT, 2017: Nols, First Responder, 2017). WOFRs and WEMTs would be able to practice spinal cooling as part of their training. Much of the procedure would be timing dependent, but require little skill. Because of this I believe it could be safely performed in an emergency situation without the oversight of a doctor. The biggest risk during this time would be the potential for secondary spinal damage while placing and removing the cooling pad. This maneuver would likely involve rolling the patient. WOFRs and WEMTs currently learn how to correctly roll a spinal patient as part of their training in spinal immobilization (Bledsoe, 2008). To avoid damaging the spine further by twisting or straining it, responders align the head, neck and torso of suspected SCI patients immediately (Bledsoe, 2008). Then, they either make a temporary apparatus or assign someone to continually support this alignment (Bledsoe, 2008). When rolling the patient, perhaps to drain their airway of fluid, or get them on a stretcher, responders pay particular attention to maintaining this alignment because of the increased vulnerability to injury in this time of motion (Bledsoe, 2008). Introducing a cooling pad would require the patient to be rolled every half hour during treatment, which would increase the likelihood of secondary injury via rolling. The risk would be limited however, due to the fact that the roll could be only a partial turn, just enough to place or remove the cooling pad, and it would be performed after measures had been taken for spinal immobilization by a trained responder.

One very legitimate concern posed by introducing cooling in backwoods environments is the risk of hypothermia. Full body hypothermia has many adverse side effects; lowering the core blood temperature can lead to a reduction in cardiac output, cardiac arrhythmia, and even death (Zhu et al., 2010). The average body temperature for humans is 98.6°F. Generally, severe hypothermia sets in when the core body temperature is below 90 °F (Donner, Mild, 2013). Still, mild hypothermia, which doesn't pose a risk of permanent damage, can occur at temperatures far above this (Donner, Mild, 2013). Secondary SCI *does* pose a serious risk of permanent damage (Zhu et al., 2010), and thus its prevention should be prioritized above the risk of inducing mild hypothermia. Still, to err on the side of caution and allow room for any inaccuracies, let's say that inducing a core body temperature lower than 93°F is unacceptable. In the simulation by Zhu

et al., a 68°F cooling pad, when applied to the spine for 30 min, reduced the temperature of the spinal cord by 4.9°F (Zhu et al., 2010). This would leave the spinal cord temperature at 93.7 °F, meaning that even the temperature in the target area would not drop below our threshold, and the core body temperature would be well above it.

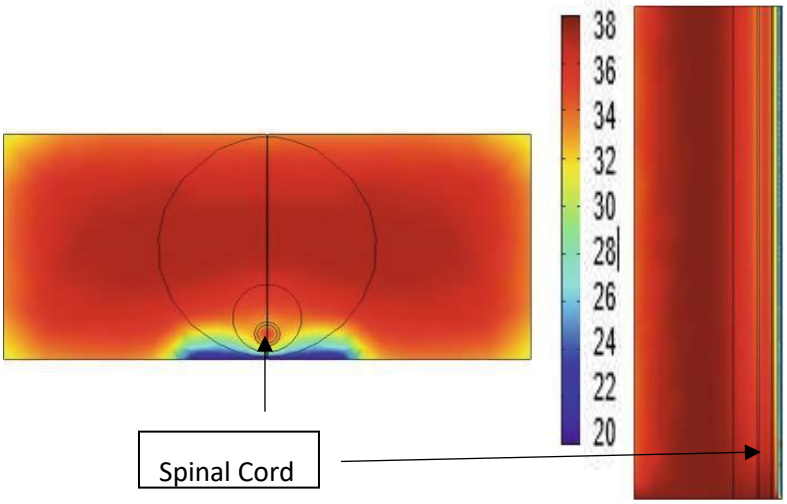

Figure 2: These temperature contours show temperature distribution after thirty minutes of cooling with the image on the left being a midline axal cross section and the image on the right being a sagittal cross section (Zhu et al., 2010). Temperature is in °C.

As you can see from Figure 2, after 30 min of cooling, the core body temperature remained constant at 98.6°F (Zhu et al., 2010). One reason the cooling may seem modest is that metabolically generated heat constantly enters the spinal region through blood perfusion and moderates the temperature decrease (Zhu et al., 2010). These experimental numbers are based on an environmental temperature of 70°F (Zhu et al., 2010). In a wilderness situation, outside temperatures are variable, as winds can suddenly pick up and the onset of night means additional cooling. On a fall day, temperatures could easily drop below 70°F rendering the numbers above inaccurate. One way to ensure internal body temperature is through use of an oral thermometer. According to NOLS, a leading organization in wilderness education and medicine, oral thermometers are highly recommended for wilderness first aid kits (Buer, 2016). Oral thermometers are small, portable, and highly accurate. By taking the patient's temperature once every ten minutes, a responder could ensure the patient's internal body temperature remained stable. In addition, wilderness first aid kits include an emergency blanket (Blanket, 2017). These highly reflective, light weight blankets are advertised to reflect back up to 80% of lost body heat (Blanket, 2017). Surrounding the patient with an emergency blanket would make it possible to keep the patient's external temperature well above 70°F even when air temperatures are much lower. Additionally, the reflective material acts as a windbreaker and prevents evaporative cooling. One factor that helps to differentiate mild hypothermia from severe hypothermia is the patient's mental awareness (Donner, Mild, 2013). Lack of mental awareness is itself a symptom of a SCI (Nicholas, et al., 2013), but a rapid decay in a patient's cognitive function would be a strong indicator that induced cooling should be immediately stopped. Because of the complicated and temperamental nature of weather, cooling should not be attempted in wet or precipitating

areas, or when temperatures are below freezing. While long-term risks associated with hypothermia are real, localized cooling has little effect on core body temperature. As an extra precaution, I recommend responders regularly take the patient's temperature, surround the patient with an emergency blanket, monitor the patient's cognitive awareness, and opt not to use cooling in stormy or freezing weather. In combination, these measures could reduce the risk of hypothermia to well within acceptable levels.

My model for external induced cooling in the wilderness, based on currently available evidence, is as follows: Chemical cooling pads are engineered to maintain a temperature of 68°F. These cooling pads are made a staple of wilderness first-aid kits. WOFR training and WEMT training includes a section on proper use of cooling pads to treat SCI. To prevent hypothermia, cooling happens in intervals where the spine is chilled for a half an hour and then rested for a half hour. Before any rolling, patient's spines are carefully immobilized; rolling is done minimally, gently, and carefully. During active cooling, the patient's temperature is measured with an oral thermometer every ten minutes; their level of awareness is also monitored. A two-hour interval of cooling is initiated forty-five minutes after injury. A second two-hour session begins after five hours, and a third starts at 20-hours and continues on until evacuation.

I urge further research into the acute use of cooling pads as a tool for first aid in backwoods situations, as I believe their careful use has the potential to be both practical and beneficial. Intentionally timed cooling can deter neurotoxic immune events, while minimally impacting neuroprotective ones; cooling pads are both effective and portable, making their transport a realistic investment in long-term wilderness safety. Together, this combination allows locally induced hypothermia to be an exciting possibility in the future of wilderness medicine.

Acknowledgments

Thanks to Dr. Kemp, David Shamritsky, and Josie Simmons for reviewing my paper, and providing valuable feedback.

Bibliography

Bledsoe, Gregory., et al. *Expedition and Wilderness Medicine*. Cambridge University Press (2008).

Bowes, Amy L., and Ping K. Yip. "Modulating Inflammatory Cell Responses to Spinal Cord Injury:

All in Good Time." Journal of neurotrauma 31.21 (2014): 1753-66. ProQuest. Web. 10 Jan. 2017.

Buer, Sarah. “27 Considerations for a Wilderness First Aid Kit.” Nols.org. (2016). Web. 6 Feb. 2017.

Cochrane, Darryl J. "Alternating Hot and Cold Water Immersion for Athlete Recovery: A Review."

Physical Therapy in Sport 5.1 (2004): 26-32. ProQuest. Web. 6 Feb. 2017

Dietrich, W. D., et al. "Hypothermic Treatment for Acute Spinal Cord Injury." Neurotherapeutics

8.2 (2011): 229-39. ProQuest. Web. 6 Feb. 2017.

Donner, Howard. “Wilderness Medicine: Mild vs. Severe Hypothermia.” Wilderness Medicine.

(2013). Video.

Donner, Howard. “Wilderness Medicine: Hypothermia Treatment.” Wilderness Medicine. (2013). Video.

"Emergency Blanket (reflective)." *Emergency Blanket (reflective)*. Emergency Essentials, n.d. Web. 06 Feb. 2017.

Hinckley, Michael. "What Chemicals Are Used in Instant Ice Packs?" *Sciencing*. N.p., n.d. Web. 22 Feb. 2017.

Khan, Sal. "Endothermic vs. Exothermic reactions." Khan Academy. N.p., n.d. Web. 09 Feb. (2017).

Lin, Vernon W., *Spinal Cord Medicine: Principles and Practice*. New York, US: Demos, (2003). ProQuest ebrary. Web. 5 Feb 2017.

McDowell, Julie., *The nervous system and sense organs.* Greenwood Press, (2004).

"Musculoskeletal Trauma: Spinal Cord Injury Management." Wilderness Medicine Newsletter.

Wilderness Medicine News Letter, 2 May 2007. Web. 21 Jan. 2017.

Nemet, Dan, et al. "Effect of Local Cold-Pack Application on Systemic Anabolic and Inflammatory

Response to Sprint-Interval Training: A Prospective Comparative Trial." European Journal of Applied Physiology 107.4 (2009): 411-7. ProQuest. Web. 6 Feb. 2017.

"NOLS | Wilderness Emergency Medical Technician." *NOLS*. N.p., n.d. Web. 09 Feb. 2017.

"NOLS | Wilderness First Responder." NOLS. N.p., n.d. Web. 09 Feb. 2017.

Parker, Steve. *The Human Body Book*. Dorling Kindersley Books, (2013).

Petrucci, Ralph H. *General Chemistry: Principles and Modern Applications*. 10th ed. Upper Saddle River:

Pearson Education International (2007) Print.

Ramer, Leanne M., Matt S. Ramer, and Elizabeth J. Bradbury. "Restoring Function After Spinal Cord Injury: Towards Clinical Translation of Experimental Strategies." *The Lancet Neurology* 13.12 (2014): 1241-56. *ProQuest.* Web. 20 Feb. 2017.

"SAM Splint." NOLS. N.p., n.d. Web. 09 Feb. (2017).

Shann, Frank. "Hypothermia for Traumatic Brain Injury: How Soon, how Cold, and how Long?" The Lancet 362.9400 (2003): 1950-1. ProQuest. Web. 6 Feb. 2017.

Theodore, Nicholas, et al. “Prehospital Cervical Spine Immobilization after Trauma.” Congress of Neurological Surgeons (2013). CNS.org. Web. 5 Feb. 2017.

Zhu, Liang et al. "Theoretical Evaluation of a Simple Cooling Pad for Inducing Hypothermia in the

Spinal Cord Following Traumatic Injury." Medical and Biological Engineering and Computing 48.2 (2010): 167-75. ProQuest. Web. 8 Jan. 2017.

“2012 Outdoor Recreation Participation Report.” The Outdoor Foundation. (2012): Web. 20. Feb 2017.