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WILDERNESS MEDICINE CLINICAL CASE DISCUSSION

An Unusual Mountain Biking Injury: Case Records of the Massachusetts General Hospital Wilderness Medicine Fellowship

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Dr Lorenzo Albala: A 30-y-old helmeted man with a history of lumbar herniation status following microdiscectomy presented after a fall while mountain biking. The patient was riding in a New England trail system when the front wheel of the bike hit a root and he lost control. He flipped over the handlebar approximately 2 mi from the trailhead. The patient reported striking his head on the ground but had no loss of consciousness. During the fall, he also recalled the end of the handlebar striking his left lower abdomen and reported immediate severe pain.

The pain abated after a few minutes, and the patient attempted to ambulate down the trail, but within 10 to 15 steps he experienced a cramping sensation in his left lower extremity extending from his thigh to his calf. The discomfort improved with rest but recurred upon attempting to walk or ride his bicycle back to the trailhead, and he was forced to stop due to pain at increasingly frequent intervals. After 15 min, he noted that the sensation in his left foot was decreased, and he described it as if "walking on foam."

Dr N. Stuart Harris: Although he struck his head, the likelihood of a significant head injury is minimal as he did not report headache or loss of consciousness. I am, however, concerned about the blunt trauma injury to the left lower quadrant. Did the patient exhibit other associated symptoms? Was the patient able to perform a physical exam at the trail side?

Dr Albala: The patient had no nausea or vomiting, and he did not report radiating pain into his flank or back. He did not note any tenderness or obvious outward signs of trauma to his head or cervical spine, and his helmet was intact. There was no external bleeding. Additionally, the patient stated that he urinated on the side of the trail and did not notice any blood.

Given the pain in his leg with ambulation, halfway to the trailhead he removed his shoes to inspect his feet. He did not appreciate any differences in perfusion. However, the ambient temperature was cool, and he had difficulty palpating his peripheral pulses.

Dr Luke Apisa: It is unlikely that the patient's abdominal pain acted as a significant distracting injury from cervical spine trauma.[1] Are abdominal injuries due to bicycle accidents common?

Dr Harris: Bicycle injuries are common in the United States and lead to approximately 500,000 emergency department (ED) visits annually. The majority of these visits are seen in the pediatric population.[2] While head trauma is the most common injury associated with bicycle accidents, visceral abdominal injuries are not uncommon.[3] A recent retrospective review in the pediatric population noted that 9% of all bicycle injuries were due to handlebar impact and contributed to almost 20% of all internal organ injuries.[4] The handlebar end has a small surface area, and the force of the impact (mass × velocity^2 / distance) can result in significant trauma to underlying structures. Handlebar injuries can include pancreatic injuries, traumatic abdominal wall hernias, duodenal hematoma, splenic and liver injuries, renal injuries, and rarely, vascular injuries.[4-9] Handlebar injuries are less common in adults, presumably because

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of well-developed abdominal wall musculature as well as the reduced likelihood of riding recklessly, in comparison to children and adolescents.[10] At this point, the patient requires evacuation and further evaluation.

Dr Apisa: The patient has injured himself about 2 mi from a trailhead. What are his options for evacuation?

Dr Albala: Land-based evacuation options are highly dependent on road proximity as well as access to communication networks. In this case, the patient was a few miles from a road but near an urban center. He was carrying his cell phone and had normal service and so could have activated emergency medical services via a 911 call at any time. However, his location in a park area would have limited traditional ambulance access to the fire road traversing the park. Local services, likely a combination of police, emergency medical technicians, and fire rescue, would have to interface with park services to plan an approach to the patient utilizing small off-road vehicles, on foot, or a combination of the two. If the patient was unable to self-evacuate at all, a litter carry for him would require at least 6 to 8 people.

On the other end of the spectrum, remote or backcountry areas with challenging terrain are infrequently serviced by roads. Mountainous and high-altitude environments and areas with thick vegetation may preclude a straightforward land-based approach and require higher level search and rescue capabilities. Helicopter or fixed-wing aircraft (including seaplane approach) and personnel with technical high-angle rescue or mountaineering skills are often required. Furthermore, the rescue personnel may need to provide a higher level of medical care as the time to reach and evacuate the patient is often prolonged.[11]

It is also likely that the aforementioned locations are beyond the reach of cellular communication. In these cases, the ideal tools involve satellite communication: personal locator beacons, satellite messengers, and satellite phones.[12] Smartphone manufacturers are currently installing satellite-enabled microchips in premium cell phones to allow for emergency satellite messaging. Satellite capability may still be impaired by the surrounding environment and may require some movement to more favorable territory.[13] Radio communications rely on line of sight; however, drone technology has been used to extend the communication reach of search and rescue teams.[14] Additionally, wearable sensors (eg, Apple watch, glucose monitors, etc.) can provide remote patient monitoring.[15]

Dr William Binder: At present, we have a young man with what appears to be a lower abdominal injury. Do any commercial medical kits contain diagnostic technology? Would further diagnostics help in this location?

Dr Harris: Mountain biking medical kits can range from equipment designed to treat minor wounds and lacerations to kits devised to treat emergent life-threatening conditions. These types of kits can include a combat application tourniquet, an EpiPen, a 6.0 endotracheal tube, a scalpel, 14-gauge decompression needles, as well as wound treatment supplies and splints. These items are potentially lifesaving, provided a rider with medical training is on scene. However, they are less advantageous for a solo rider or if an injured rider is accompanied by someone without necessary medical training.

I am not aware of any commercial kit that includes a handheld ultrasound system. It is possible that use of a portable unit could lead to a field diagnosis, such as intra-abdominal bleeding through a positive focused assessment with sonography for trauma (FAST) exam or potentially even a vascular injury. However, this would not change management, aside from reinforcing the need for rapid evacuation.

Dr Albala: The patient managed, over 1 h, to get to the trailhead and to his car. He drove for about 30 min to a trauma center, bypassing a closer ED. Upon arrival to the trauma center, his clothing was removed, and the ED provider noted that his left foot was pale and cool (Figure 1). No dorsal pedis or posterior tibialis pulse was noted on palpation or on Doppler. The patient also reported left lower quadrant abdominal pain.

A CT angiogram of the abdominal aorta with lower extremity runoffs was performed (Figure 2) and revealed a complete occlusion of the left external iliac artery with

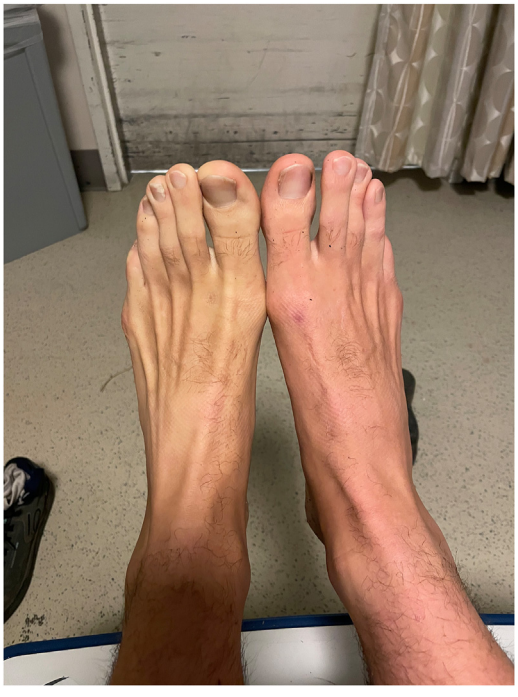

Figure 1. The patient's left foot was pale and cool to touch.

distal recanalization. A posttraumatic dissection flap extended from the posterior femoral artery and superficial femoral artery bifurcation to the distal left femoral artery. There was no evidence of a flap more proximally in the aorta. The right-sided vascular tree was patent.

Dr Binder: How common are vascular injuries in biking? What are the injury patterns reported in mountain biking? I have not seen this previously.

Dr Stephanie Lareau: In the United States, there are more than 8 million mountain bikers, and there are more than 30 million worldwide. Injury rates are high. Some studies report up to 40 injuries per 1000 h of riding, although other reviews have noted a lower incidence.[16,17] Limb or life-threatening injuries occur at a rate of 2.5 per 1000 h of riding.[16] Numerous North American ski resorts offer lift-accessed terrain, and this has resulted in steeper, longer, and more technical rides, increasing the risk for serious injuries.[18]

As expected, abrasions and bruises are the most common injuries noted in mountain biking. Fractures are also common, with the clavicle followed by the distal radius and scaphoid being the most frequently fractured bones.[17] Head and traumatic spinal injuries are also noted. The British Columbia Trauma Registry reported that of the 399 mountain bikers admitted to trauma centers, 12% had head injuries and 12% had spine fractures.[19] Of the 5% of abdominal injuries reported by the British Columbia Trauma Registry, no vascular injuries were cited.[19] While vascular injuries secondary to handlebar trauma have been reported in pediatric bicycle accidents, there is a paucity of literature on adult vascular handlebar injuries. One case report describes a celiac artery dissection after a mountain bike crash with a grade 3 of 4 splenic laceration with hemoperitoneum.[20] Overall, vascular injuries appear to be rare within reported mountain biking injuries.[17,21,22]

Dr Apisa: What happened after the CT angiogram?

Dr Albala: The patient was started on a heparin infusion and taken to the operating room for vascular surgery. At approximately 7 h after initial injury, the patient underwent a thrombectomy and external iliac stent insertion.

Dr Sunita Srivastava: There were several factors that mandated an emergent approach. The first was that the patient was acutely symptomatic and, being young without pre-existing collaterals as we see in older patients with atherosclerotic disease, there were no collaterals to ameliorate the acute loss of flow from the injury. In addition, acute limb ischemia can only be tolerated for 6 to 8 h without impacting peripheral nerve and muscle function. The ischemia to both the peripheral nerves and muscles could have resulted in permanent impairment.

Anticoagulation alone would not have been sufficient to clear the thrombosis incited from the blunt injury, but rather, it prevented thrombus propagation until the vascular injury could be corrected. The patient required a femoral exploration due to the extension of the thrombus/dissection to the femoral bifurcation, and after this was addressed by cutdown and exploration with repair, the more proximal external iliac thrombosis was addressed with self-expanding stent placement. Additionally, the patient's external oblique fascia was torn, indicating that the handlebar pushed into the retroperitoneal space, injuring the external iliac artery. Manual inspection of the defect led to the retroperitoneal space and vessel. The fascia was repaired after reestablishing inline flow to the limb. Fasciotomies were not performed because the calf was soft and not edematous upon inspection during the groin closure likely due to expeditious restoration of flow. Compartment syndrome requiring fasciotomies can occur after establishing perfusion following a prolonged period of ischemia. Fortunately, this did not occur.

Dr Lareau: What was the outcome?

Dr Albala: The heparin infusion was discontinued 5 h postoperatively. The patient was started on daily 81 mg aspirin and 75 mg clopidogrel. He was discharged on postoperative day 3. Lower extremity ankle-brachial index and stent Doppler ultrasonography were normal at 3 wk and 3 mo postoperatively. Clopidogrel was discontinued

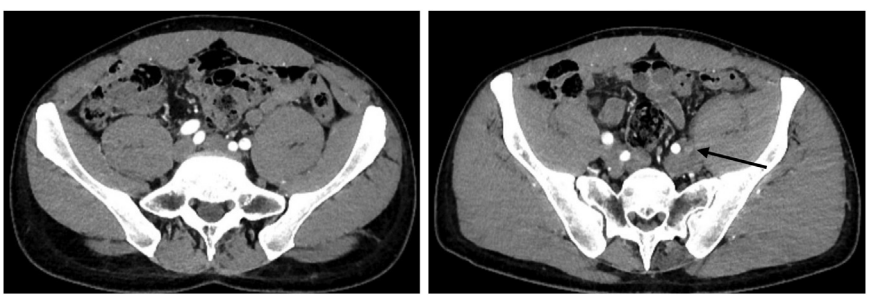

Figure 2. Occlusion of left external iliac artery with distal recanalization. Note that the left external iliac artery is not perfused at this level (right, arrow).

after 1 mo. At the 3-mo postoperative visit, he denied any claudication symptoms, pain, or paresthesias. The patient was counseled about continuing lifelong daily aspirin as well as prophylactic anticoagulation for long flights.

Conclusion

Mountain biking injuries are most commonly musculoskeletal. In blunt trauma to the abdomen, however, there is a risk of solid organ injury and vascular injury. There are minimal effective treatments for these conditions in the field, highlighting the importance of rapid evacuation to definitive medical care. Thorough physical exam and high suspicion of serious injury were important in this patient's successful outcome.

Disclosures: William Binder is Editor-in-Chief of WEM and Stephanie A. Lareau is Education editor of WEM. Per WEM policy, they had no involvement in the editorial or peer review process for this manuscript.

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ORIGINAL RESEARCH

A Randomized Phase 2 Study to Evaluate Efficacy and Safety of AR36 for Prevention of Acute Mountain Sickness

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Introduction—AR36 is a pharmaceutical-grade plant extract used to support cardiovascular health in traditional Chinese medicine. Studies suggest that AR36 may prevent acute mountain sickness (AMS) during gradual ascent to high altitude. This randomized, placebo-controlled Phase 2 trial aimed to evaluate dosing regimens and assess efficacy and safety of AR36 for AMS prevention during rapid ascent.

Methods—Participants received placebo, low-dose AR36 (225 mg twice daily for 14 d prior and 5 d at altitude), or high-dose AR36 (12 d placebo, 300 mg twice daily for 2 d prior and 5 d at altitude). The primary efficacy outcome was 1993 Lake Louise Scoring System (LLSS) score on the morning after ascent. Safety was assessed through the proportion of treatment-emergent adverse events (TEAEs).

Results—One hundred thirty-two participants were randomized. Mean±SD age was 31.4±8.6 (range, 19–54) y. Baseline characteristics did not differ across groups. Lake Louise Scoring System scores on Day 16 in the placebo, low-dose, and high-dose groups were 4.03 (2.88), 4.42 (3.17), and 3.5 (2.31), respectively (placebo versus low-dose, P=0.462; placebo versus high-dose, P=0.574; n=110). The incidence of AMS on Day 16 was 66.7% in the placebo, 61.1% in the low-dose, and 55.3% in the high-dose group (P=0.66). The proportion of TEAEs in the placebo, low-dose, and high-dose groups was 38.4% (81), 28.4% (60), and 33.2% (70), respectively (P=0.205; n=127). There was no statistical difference between groups in LLSS, incidence of AMS, or TEAEs.

Conclusions—AR36 did not improve LLSS or AMS incidence using the current regimens. AR36 was well tolerated.

Keywords: Dantonic, Danshen, high-altitude sickness, high-altitude illness, T89

Introduction

Extended stay at high altitude has become increasingly common for recreation, work, and military purposes. Acute mountain sickness (AMS) describes a constellation of symptoms (including headache, gastrointestinal discomfort, fatigue, dizziness, and sleep disturbances) occurring after ascent to altitudes above 2500 m.[1] The pathophysiology of AMS has not been fully elucidated. However, research suggests that hypobaric hypoxia may lead to hyperventilation, fluid retention, altered gas exchange, increased intracranial pressure, and a systemic inflammatory state,[2-4] all of which may underlie AMS symptoms.[5] In rare cases, AMS can progress to high-altitude cerebral edema or high-altitude pulmonary edema, which may be life-threatening.[1]

Preacclimatization by gradual ascent may reduce the risk of developing AMS.[6] If gradual ascent is not possible, pharmacologic prophylaxis is recommended.[7] Acetazolamide, a carbonic anhydrase inhibitor, is first-line therapy for AMS prevention.[8] Although effective, acetazolamide can mimic AMS symptoms and may be associated with adverse effects that are poorly tolerated.[8,9] The efficacy of acetazolamide during rapid ascent to high altitude varies across studies depending on the dose used and rate of ascent.[8,10-16] Following rapid ascent to 3810 m, where the current study was conducted, the

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incidence of AMS after acetazolamide pretreatment was 39 to 55%.[8,11-13] Rates in placebo at the same location have been reported as 63 to 69%.[12,17] Effectiveness of acetazolamide may be reduced in individuals who are partly acclimatized.[18] Ibuprofen treatment, which is readily available and commonly used, led to AMS rates of 43 to 62%.[13,17] These findings highlight the need for additional, alternative pharmacologic interventions that are both effective and well tolerated.

AR36, also known as T89, Dantonic, or Compound Danshen Dripping Pills, is a modernized preparation of a traditional Chinese medicine composed of pharmaceutical-grade extracts from the plants Danshen (Radix *Salvia miltiorrhiza*) and Sanqi (Radix *Panax notoginseng*).[19,20] AR36 also contains Bing Pian (borneol) derived from the plant *Dryobalanops aromatica*, which enhances absorption of Danshen and Sanqi.[19,20] AR36 has traditionally been used to treat myocardial ischemic diseases in China and is approved by the National Medical Products Administration for treatment of angina pectoris.[19] AR36 has been shown to increase oxygen saturation during high-altitude exposure[20] and reduce proinflammatory cytokines,[21,22] which may reduce the inflammatory state that is thought to partly underlie AMS development. In addition, *P notoginseng* was shown to improve exercise tolerance in mice at simulated high altitude.[23]

In a placebo-controlled pilot study conducted in 2014, pretreatment with AR36 during gradual ascent reduced the risk of developing AMS by 19% and increased exercise capacity.[20] The present prospective, double-blind, randomized, placebo-controlled Phase 2 trial aimed to assess the efficacy and safety of 2 AR36 dose regimens for prevention of AMS during rapid ascent to 3810 m to assess the feasibility of a trial at this location and to inform the design of a proposed pivotal Phase 3 trial in a US population.

Methods

ETHICAL APPROVAL

Study protocols were approved by the University of California San Francisco Institutional Review Board (IRB) and conformed to the Declaration of Helsinki (IRB number: 17-23953; trial registration: ClinicalTrials.gov NCT03552263). All participants provided written informed consent prior to study initiation.

STUDY PARTICIPANTS

Participants were recruited via social media and local advertisements and were predominantly from the San Francisco Bay area but were accepted from farther away if they met study inclusion criteria and were able to attend all visits. Participants were prescreened to determine feasibility of participation in study procedures and to confirm lowland dwelling status. All participants were unacclimatized, healthy, nonsmoking adults aged 18 to 55 y who resided less than 1000 ft (approximately 305 m) above sea level. This age limit was selected to minimize the risk of occult comorbid cardiac conditions in older participants, because of planned daily exercise to exhaustion at high altitude. Participants were also required to pass a drug screen and physical examination and have normal baseline laboratory values (hematology, clinical biochemistry, and urinalysis) prior to enrollment. Major exclusion criteria included a medical history of cardiovascular, cerebrovascular, respiratory, renal, hepatic, or other significant comorbid conditions; blood oxygen saturation (SpO_2) less than 95% at sea level; and surgery, blood donation, or treatment with any medications aside from oral contraceptives within 14 d of screening and during the study. The complete list of inclusion and exclusion criteria is provided in online Supplemental Table 1.

STUDY DESIGN

This Phase 2 study was designed to perform an exploratory analysis comparing efficacy and safety of 2 different AR36 dosing regimens in a healthy US population in order to optimize trial logistics and plan future Phase 3 pivotal trials. The targeted enrollment of 132 participants (44 per group) was based upon a previous trial of gradual ascent in 141 participants[20] as well as the anticipated rates of AMS at this elevation.

This study investigated 2 different AR36 dosages and regimens. We hypothesized that a lower dose with a longer pretreatment period could gradually increase plasma drug levels and have a similar efficacy profile and a better safety profile compared with a shorter, higher-dose regimen. Participants were randomized 1:1:1 by block randomization to 3 treatment groups: placebo, low-dose AR36 (14 d treatment before ascent continued 5d at altitude), and high-dose AR36 (12 d placebo, then 2 d treatment before ascent and continued 5d at altitude). The low-dose AR36 group received a constant dose of 225 mg twice daily for 14 d at sea level and for 5 d after ascent. The high-dose AR36 group received placebo twice daily for the first 12 d at sea level, followed by 300 mg twice daily for 2 d at sea level and for 5 d after ascent. The placebo group received placebo treatment twice daily for 14 d at sea level and for 5 d after ascent (Figure 1).

Investigators and participants remained blinded to group assignments until trial completion. To maintain blinding, all investigational product capsules provided by

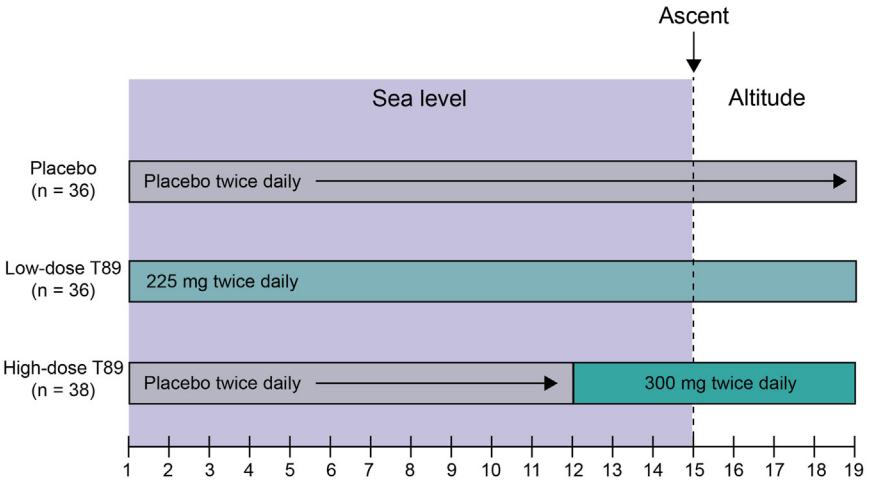

Figure 1. Study drug and ascent schedule for each treatment group. n=110.

the manufacturer were identical. Compliance with treatment regimens was self-reported by participants via a drug and symptom log from Days 1 to 14 and was ensured by direct observation on Days 15 to 19. On Day 15, participants ascended from sea level to 3810 m (Nello Pace Laboratory at Barcroft Station, White Mountain Research Center) by automobile over 8 to 10 h and remained there until completion of the study on Day 19. Study data were collected over 2 operational seasons (June–October 2018 and June–October 2019).

OUTCOMES

The primary efficacy outcome was mean 1993 Lake Louise Scoring System (LLSS) score on Day 16 (the morning after ascent). Secondary efficacy outcomes included mean SpO_2, exercise tolerance, systolic and diastolic blood pressure (BP), heart rate, and area under the curve (AUC) of the 1993 LLSS–time curve during rapid ascent and stay at high altitude (Days 15–19). Area under the curve was used as a novel method for assessing a composite of severity and duration of AMS. Relative risk for the development of AMS over the entire study period and the total incidence of AMS the morning after arrival were also calculated. As acute acclimatization is generally thought to occur within 3 to 4 d at this altitude, data from Days 15 to 18 were used for analysis of SpO_2, BP, and heart rate. The primary safety outcome was the proportion of treatment-emergent adverse events (TEAEs) across treatment groups.

ACUTE MOUNTAIN SICKNESS ASSESSMENT

Acute mountain sickness symptoms were assessed using the 1993 LLSS at each prealtitude visit and twice daily while at altitude.[24] This version of the LLSS was used because the revised score[25] only became available in 2018, after IRB and US Food and Drug Administration approval and after study initiation. The 1993 LLSS contains 3 domains: a self-administered questionnaire for headache, gastrointestinal symptoms, fatigue/weakness, dizziness/lightheadedness, and difficulty sleeping; a functional assessment of the degree to which AMS symptoms caused a reduction in activity; and a clinical assessment of mental status, ataxia, and peripheral edema. All clinical assessments were performed by study investigators. Each symptom was scored as 0, 1, 2, or 3, indicating no, mild, moderate, or severe symptoms, respectively. Pain from headache was assessed using a visual analog scale.[26-28] Acute mountain sickness was defined as a mean combined 1993 LLSS score of ≥3 in the presence of a headache and at least 1 other symptom.[24] A post hoc calculation of LLSS score using the 2018 definition was also performed.

LABORATORY AND PHYSIOLOGIC ASSESSMENTS

Physiologic measurements, including SpO_2, BP, and heart rate, were obtained after at least 5 min of rest in a seated position at the following time points: enrollment (before initiation of drug), on the day before ascent (day 14), on the day of ascent (day 15), and on each day after arrival (Days 16–19). Blood oxygen saturation and heart rate were monitored using a Radical-7 Pulse CO-Oximeter (Masimo Co, Irvine, CA) applied to participants' index fingers. For each sea level visit, a single measurement was taken. At altitude, these data were collected 4 times per day: before breakfast, before lunch, before dinner, and before sleep. Laboratory assessments

(hematology, clinical biochemistry, and urinalysis) and electrocardiograms were also obtained at sea level and at altitude.

EXERCISE TEST

At sea level, participants completed physiologic and AMS assessments followed by an exercise tolerance test consisting of cycling to exhaustion using a ramp protocol. After a 3-min unloaded warm-up at 30 W, resistance was increased to a starting power corresponding to participant weight; exercise load started at 110 W for participants weighing ≥60 kg and at 90 W for those weighing <60 kg. Regardless of starting weight, the load was increased by 5 W every 20 s until participants reached exhaustion, which was marked by cadence decreasing below 40 revolutions/min. At altitude, this test was performed in the afternoon on the day of arrival (Day 15) following physiologic and AMS assessments and every morning for subsequent days (Days 16–19) following physiologic and AMS assessments. The exercise protocol was designed to capture maximal oxygen consumption ($\dot{V}O_2$ max) and was performed on a Monark 939E Novo computer-controlled cycle ergometer (Monark Exercise, Vansbro, Sweden), which maintained target power output regardless of cadence. Blood lactate levels were measured by finger prick immediately before exercise and upon completion of the exercise protocol to verify exertion level. Differences in maximum power output during exercise (W/kg) from sea level to altitude between AR36 and placebo groups were computed.

EFFICACY ANALYSIS

Descriptive statistics, including mean, standard deviation, standard error of the mean, median, interquartile range, and range, were reported for continuous variables. Categorical variables were summarized using counts and percentages. Statistical analyses for detecting significant differences from baseline (before ascent) or compared with placebo included the Kruskal-Wallis test, Mann-Whitney *U* test, χ^2 test, Tukey's 2-sided test, and analysis of variance. Alpha was set to 0.05. Analyses were performed using Prism 9.0 (GraphPad Software, San Diego, CA) and R 3.1.1 (open source; R-project.org).

SAFETY ANALYSIS

Safety analyses were performed in all participants treated with at least 1 dose of the study drug or placebo. At sea level, AMS symptoms were included as adverse events because of the lack of confounding factors. At altitude, however, AMS symptoms were not included as adverse events unless they were severe and affected study participation since they were already captured by the LLSS. As such, AMS symptoms resulting in study withdrawal were recorded as severe adverse events because of their rarity at this altitude. The Medical Dictionary for Regulatory Activities was used to classify all adverse events according to organ system and preferred term. Severity of TEAEs was assessed using Common Terminology Criteria for Adverse Events, version 5.5.

Results

STUDY PARTICIPANTS

In total, 132 participants (44 placebo, 44 low-dose AR36, and 44 high-dose AR36) were randomized. Baseline characteristics were not statistically different across treatment groups (Table 1). Fifty-seven participants (43%) were female and 70 (53%) were White. Mean age was 31.4±8.6 (range, 19–54) y. Mean body mass index for the study population was 23.4±3.0 kg/m^2. Overall, 22

Table 1. Baseline participant characteristics

Characteristics	*Placebo n=44*	*Low-dose T89 n=44*	*High-dose T89 n=44*	*Total N=132*
Age (y), mean (SD)	32.0 (8.7)	30.8 (8.3)	31.5 (8.8)	31.4 (8.6)
Female, n (%)	18 (40.9)	20 (45.5)	19 (40.9)	57 (43.2)
Height (cm), mean (SD)	172.4 (9.7)	171.2 (11.6)	171.2 (7.9)	171.6 (9.8)
Weight (kg), mean (SD)	69.9 (13.6)	69.1 (10.6)	68.8 (11.8)	69.2 (11.9)
BMI (kg/m^2), mean (SD)	23.4 (3.2)	23.6 (3.0)	23.3 (2.7)	23.4 (3.0)
Ethnicity, n (%)				
Asian	10 (22.7)	14 (31.8)	10 (22.7)	36 (27.3)
Black	2 (4.6)	3 (6.8)	2 (4.6)	7 (5.3)
White	24 (54.6)	22 (50.0)	27 (61.4)	70 (53.0)
Hispanic	9 (20.5)	8 (18.2)	7 (15.9)	23 (17.4)
Mixed/other	6 (13.6)	3 (6.8)	4 (9.1)	13 (9.9)

BMI, body mass index.

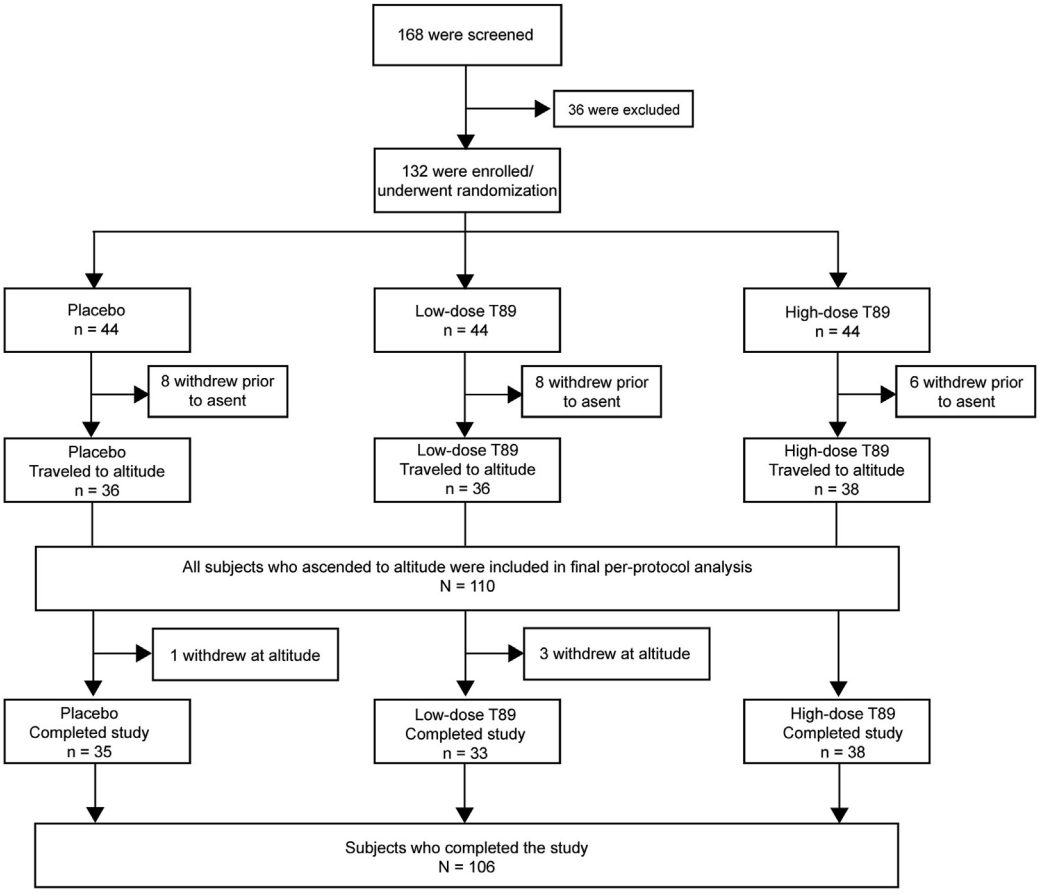

Figure 2. Participant flow diagram. N=132.

participants withdrew from the study before ascent to altitude. Of these, 11 were withdrawn after inclement weather made Barcroft Station inaccessible, 2 were withdrawn because of consumption of prohibited concomitant medications, and 9 were lost to follow-up. Of the 110 participants who ascended, 4 withdrew from the study at altitude and 106 completed all study visits (Figure 2). Compliance was 100% in both AR36 groups on Days 15 to 19 as the drug was directly administered.

EFFICACY ANALYSIS

A total of 110 participants (36 placebo, 36 low-dose AR36, and 38 high-dose AR36) reached the planned altitude and were included in the efficacy analysis. Using the 1993 consensus definition, LLSS scores on the morning after ascent (Day 16) in the placebo, low-dose, and high-dose AR36 groups were 4.03 (2.88), 4.42 (3.17), and 3.5 (2.31), respectively (placebo versus low-dose, P=0.462; placebo versus high-dose, P=0.574) (Table 2). There were no significant differences in 1993 LLSS scores on any of the days spent at altitude (Days 15−19) (Figure 3, Table 2). Post hoc analysis using the 2018 LLSS consensus definition showed a trend toward lower LLSS score in the AR36 groups compared to the placebo group, but this was not significant (see online Supplemental Figure 1). Separate analyses were performed for headache scores using the 1993 LLSS consensus definition (see online Supplemental Table 2). Headache scores in the placebo, low-dose, and high-dose AR36 groups were 1.06 (0.92), 1.33 (1.04), and 1.00 (0.84), respectively (placebo versus low-dose, P=0.34; placebo versus high-dose, P=0.95).

There were no sex differences in 1993 LLSS score in either the placebo or low-dose AR36 groups. Interestingly, females in the high-dose AR36 group had higher LLSS scores compared to males, although post hoc analysis did not identify a difference at any specific time point (P<0.001) (see online Supplemental Table 3). Acute mountain sickness incidence on the morning of Day 16 was 66.7% in the placebo group, 61.1% in the low-dose AR36 group, and 55.3% in the high-dose AR36

Table 2. Mean 1993 Lake Louise Scoring System score at altitude

	Placebo n=36		*Low-dose T89 n=36*		*High-dose T89 n=38*	
	Mean LLSS score	*SD*	*Mean LLSS score*	*SD*	*Mean LLSS score*	*SD*
Day 15 AM	0.42	1.11	0.39	0.90	0.29	0.69
Day 15 PM	1.44	1.21	1.67	1.51	1.95	2.32
Day 16 AM	4.03	2.88	4.42	3.17	3.50	2.31
Day 16 PM	2.36	1.84	2.94	2.42	2.79	2.47
Day 17 AM	3.22	2.04	2.57	2.34	2.39	2.55
Day 17 PM	2.06	1.39	1.68	1.32	1.68	1.73
Day 18 AM	1.94	2.01	1.65	1.41	1.50	1.62
Day 18 PM	1.91	1.87	1.59	1.54	1.74	1.77
Day 19 AM	1.66	1.51	1.52	1.52	1.19	1.56
Day 19 PM	1.09	1.44	0.97	1.42	0.74	0.92

LLSS, Lake Louise Scoring System.

group (P=0.66). The relative risk (95% CI) for AMS across the entire study period was 0.82 (0.59−1.11) in the low-dose AR36 group and 0.85 (0.62−1.13) in the high-dose AR36 group (Figure 4). The AUC of the 1993 LLSS−time curve, a measure of the total AMS experience over the period at high altitude, was 19.37 (3.92), 18.71 (4.1), and 17.25 (4.2) in the placebo, low-dose, and high-dose groups, respectively (P=0.931) (Figure 5).

Compared with the low-dose group, the high-dose AR36 group demonstrated higher SpO_2 at bedtime on Day 15 (low-dose AR36, 81.91 [5.16]; high-dose AR36, 84.74 [4.67]; P=0.045) and at breakfast on Day 18 (low-dose AR36, 86.44 [5.37]; high-dose AR36, 89.92 [3.84]; P=0.008)] (Figure 6; see online Supplemental Table 4). No differences were observed in BP (see online Supplemental Figure 2 and Supplemental Table 5), heart rate (see online Supplemental Figure 3 and Supplemental Table 6), or exercise tolerance (Table 3) between placebo and AR36 groups on any days at altitude.

SAFETY ANALYSIS

A total of 127 participants received at least 1 dose of the study drug or placebo and were included in the safety analysis. Duration of exposure to the study drug was 0 d in the placebo group, 19 d in the low-dose AR36 group, and 7 d in the high-dose AR36 group. There was no significant difference in the proportion of TEAEs across treatment groups (placebo, 38.4% [81]; low-dose AR36, 28.4% [60]; high-dose AR36, 33.2% [70];

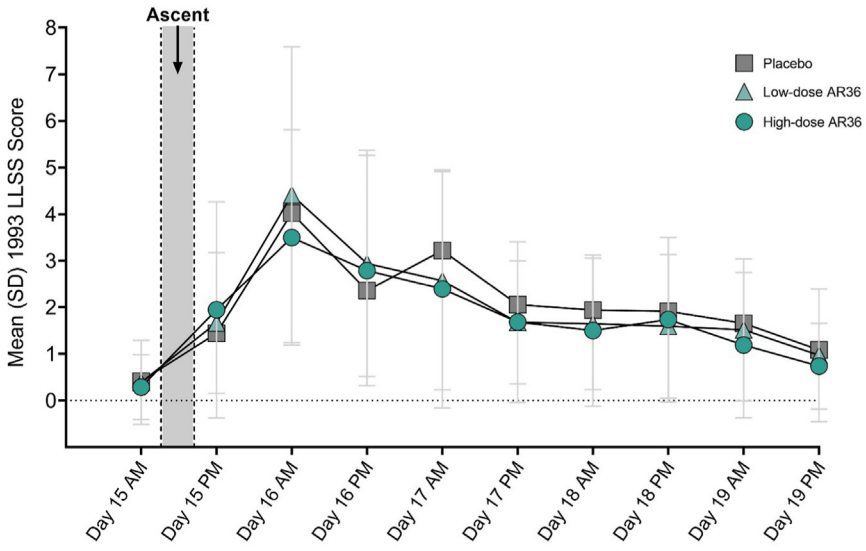

Figure 3. Mean±SD LLSS scores for the entire stay at altitude (Days 15−19) using the 1993 consensus definition. Day 15, n=110; Day 19, n=106. LLSS, Lake Louise Scoring System; SD, standard deviation.

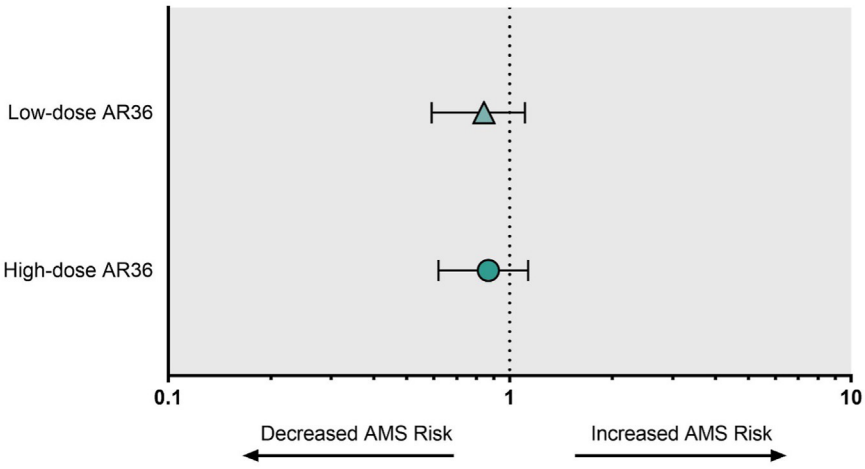

Figure 4. Relative risk for AMS in the low-dose AR36 and high-dose AR36 groups. n=110. AMS, acute mountain sickness.

P=0.205). Overall, 211 TEAEs were reported in 80 participants (63%), and 94% of TEAEs were mild. The most frequently reported TEAE classes included gastrointestinal disorders (57 TEAEs in 39 participants; 31%), nervous system disorders (48 TEAEs in 37 participants; 29%), respiratory disorders (28 TEAEs in 20 participants; 16%), general and administration site conditions (18 TEAEs in 16 participants; 13%), and musculoskeletal disorders (19 TEAEs in 13 participants; 10%) (Table 4, see online Supplemental Table 7).

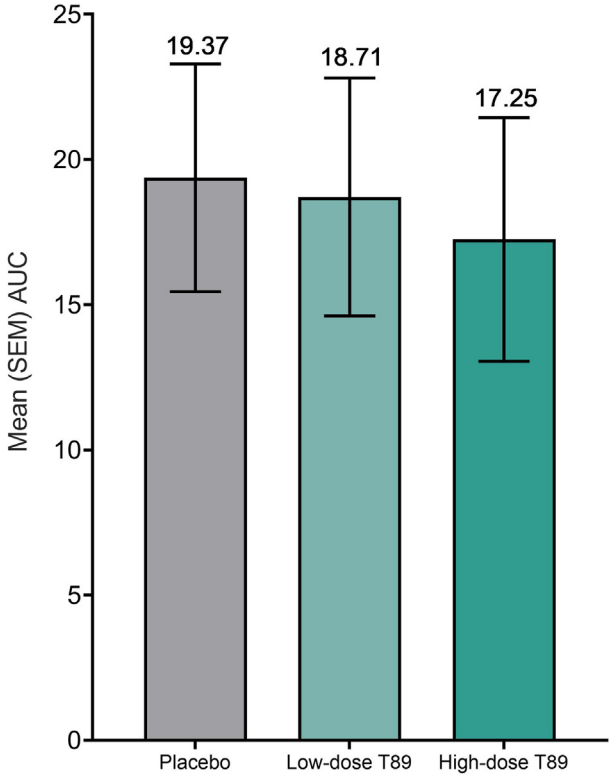

Figure 5. Mean±SEM AUC of the Lake Louise Scoring System–time curve for participants who completed all Lake Louise Scoring System assessments during the study. n=106. AUC, area under the curve; SEM, standard error of the mean.

Three of the 4 participants who withdrew from the study at altitude were from the low-dose AR36 group, and 1 was from the placebo group. Two participants (low-dose AR36 group and placebo group) voluntarily withdrew because of intolerable AMS symptoms. One participant from the low-dose AR36 group was evacuated from the altitude station and withdrawn for safety reasons after he developed high-altitude pulmonary edema on Day 18. Because of the clear temporal relationship between ascent and symptom resolution on descent, this event was deemed unrelated to drug administration. One participant from the low-dose AR36 group was withdrawn because of elevation in transaminases on Day 16. Both aspartate aminotransferase and alanine aminotransferase normalized within 1 wk when re-evaluated at sea level.

Discussion

This Phase 2 study was designed to explore the efficacy and safety of AR36 in healthy US participants during rapid ascent to altitude and to determine appropriate dosing regimens and operational study procedures. Compared with placebo, the 2 AR36 dosing regimens did not show a significant difference in the primary outcome of 1993 LLSS score on the morning after ascent (Day 16), nor did they show a difference in relative risk for the development of AMS over the course of the study.

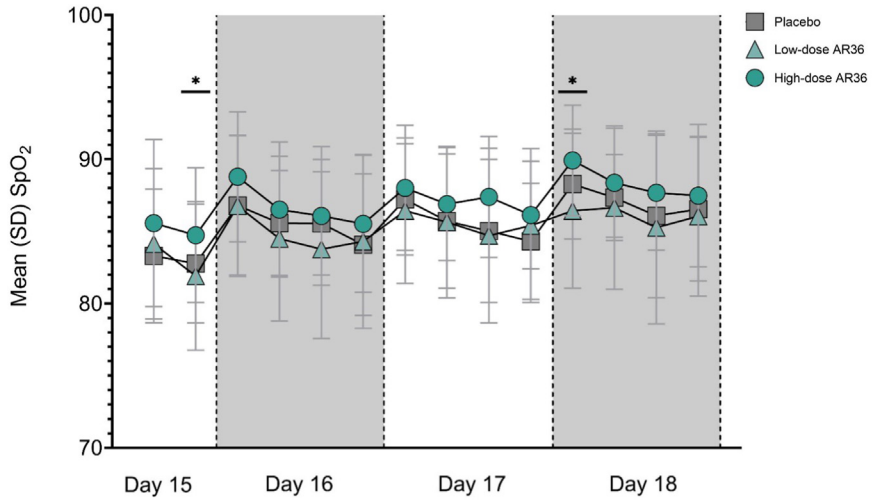

Figure 6. Mean±SD SpO_2 values at high altitude (Days 15−18). Day 15, n=110; Day 18, n=106. SD, standard deviation; SpO_2, blood oxygen saturation. *$P<0.05$

However, higher LLSS scores in females in the high-dose AR36 group suggest that there may be sex differences in the effects of AR36, which may warrant further investigation in a subsequent trial. Administration of AR36 appeared to be well tolerated, with 94% of all TEAEs being of mild severity, and with most adverse events recorded as mild gastrointestinal upset or headache prior to ascent (these symptoms were captured by the 1993 LLSS at altitude). The safety analysis did not show a higher proportion of TEAEs in the AR36 groups compared with placebo, even at the higher dose.

We aimed to determine whether a longer, low-dose regimen versus a shorter and more feasible high-dose regimen would yield similar treatment effects. There did not seem to be an advantage to a longer, lower dose regimen, as neither reached significance for AMS incidence or LLSS score. Most physiologic variables were unchanged, but high-dose AR36 was associated with higher SpO_2 compared with that in the low-dose AR36 group. Although not significantly different, lower AMS incidence, lower LLSS AUC, and lower LLSS scores may have reached significance with a sample size of 150 to 200 subjects, which should be considered in future trials. A higher dose of AR36 over a shorter period may be more practical and may justify administration using this regimen in future studies. In addition, the AR36 dosages in this study may have been too low to produce a significant effect as measured by the LLSS. Notably, the AR36 dosages administered in this study were both lower and less frequent than an earlier randomized, placebo-controlled pilot study that showed lower AMS incidence with Compound Danshen Dripping Pills during gradual ascent to altitude.[20] Higher doses of AR36 than were used in this trial may be required for the compound to be effective.

Although AR36 did not result in a significant reduction in AMS incidence or a difference in exercise tolerance, high-dose AR36 did result in a modest but

Table 3. Mean maximum power output during exercise and change in power from baseline

	Power (W/kg)			*Δ Power (W/kg)*		
	Placebo (SD)	*Low-dose T89 (SD)*	*High-dose T89 (SD)*	*Placebo (SD)*	*Low-dose T89 (SD)*	*High-dose T89 (SD)*
Day 1	3.0 (0.57)	2.98 (0.74)	2.99 (0.61)	–	–	–
Day 14	3.05 (0.58)	3.01 (0.73)	3.04 (0.62)	0.04 (0.12)	0.03 (0.17)	0.06 (0.17)
Day 15	2.57 (0.45)	2.55 (0.54)	2.54 (0.47)	−0.44 (0.21)	−0.43 (0.29)	−0.45 (0.25)
Day 16 (12 h)	2.61 (0.42)	2.54 (0.55)	2.58 (0.46)	−0.42 (0.24)	−0.44 (0.34)	−0.43 (0.26)
Day 17 (36 h)	2.56 (0.55)	2.55 (0.53)	2.59 (0.49)	−0.44 (0.29)	−0.44 (0.39)	−0.42 (0.26)
Day 18 (60 h)	2.60 (0.43)	2.58 (0.52)	2.60 (0.48)	−0.42 (0.27)	−0.42 (0.43)	−0.38 (0.25)
Day 19 (84 h)	2.67 (0.47)	2.58 (0.54)	2.56 (0.45)	−0.37 (0.26)	−0.37 (0.37)	−0.43 (0.27)

Table 4. Summary of treatment-emergent adverse events by organ system

Participants, n (%) with a total of [x] TEAEs	*Placebo (n=42)*	*Low-dose T89 (n=42)*	*High-dose T89 (n=43)*
Total	26 (61.9) [81]	30 (71.4) [60]	24 (55.8) [70]
Ear and labyrinth disorders Motion sickness, tinnitus	1 (2.4) [1]	0	1 (2.3) [1]
Eye disorders Eye discomfort	1 (2.4) [1]	0	0
Gastrointestinal disorders Abdominal discomfort, abdominal distension, abdominal pain, abdominal pain upper, abdominal pain lower, diarrhea, dry mouth, dyspepsia, dysphagia, eructation, flatulence, frequent bowel movements, gastrointestinal pain, gastroesophageal reflux disease, nausea, vomiting	14 (33.3) [21]	15 (35.7) [18]	10 (23.3) [18]
General/administration site conditions Chest discomfort, chest pain, edema (peripheral), fatigue, feeling hot, hangover, pain, pyrexia	6 (14.3) [6]	4 (9.5) [4]	6 (14.0) [8]
Infections and infestations Nasopharyngitis, respiratory tract infection	3 (7.1) [3]	2 (4.8) [2]	2 (4.7) [2]
Investigations Abnormal QRS axis, blood pressure increase, hepatic enzyme increase, low voltage electrocardiogram	3 (7.1) [4]	3 (7.1) [3]	2 (4.7) [2]
Metabolic and nutritional disorders Decreased appetite	0	1 (2.4) [1]	0
Musculoskeletal and connective tissue disorders Arthralgia, flank and neck pain, joint swelling, muscle spasms, myalgia, pain in extremity, temporomandibular joint syndrome	3 (7.1) [5]	2 (4.8) [3]	8 (18.6) [11]
Nervous system disorders Cluster headache, dizziness, dysgeusia, head discomfort, headache, hypoesthesia, lethargy, paresthesia, parosmia and poor sleep quality, presyncope, somnolence, syncope, tension headache	15 (35.7) [22]	12 (28.6) [14]	10 (23.3) [12]
Psychiatric disorders Abnormal dreams, anxiety, insomnia and restlessness, irritability	3 (7.1) [3]	0	2 (4.7) [3]
Reproductive disorders Breast pain and tenderness, dysmenorrhea, priapism, vaginal hemorrhage	3 (7.1) [3]	1 (2.4) [2]	3 (7.0) [3]
Respiratory, thoracic, and mediastinal disorders Acute pulmonary edema, cough and allergic cough, dysphonia, epistaxis, nasal congestion, oropharyngeal pain, painful respiration and respiratory tract congestion, paranasal sinus discomfort, pharyngeal paresthesia, throat irritation	9 (21.4) [12]	8 (19.0) [9]	3 (7.0) [7]
Skin and subcutaneous disorders Night sweats, rash, and photosensitivity reaction	0	2 (4.8) [2]	1 (2.3) [1]
Surgical and medical procedures Endodontic procedure	0	0	1 (2.3) [1]
Vascular disorders Flushing, and hot flush, hypertension	0	2 (4.8) [2]	1 (2.3) [1]

TEAEs, treatment-emergent adverse events.

significantly higher SpO_2 at altitude compared with low-dose AR36. This improvement in oxygenation may have resulted in increased oxygen delivery to tissues and a resultant decrease in tissue hypoxia. Several studies have shown a correlation between hypoxemia and development of AMS,[29-35] and prior research has shown that acetazolamide use was associated with higher SpO_2 compared with placebo.[36] However, other studies have failed to show that higher oxygen saturation was protective against AMS.[37,38] Therefore, the modest increase in peripheral arterial oxygenation detected in this study following treatment with high-dose AR36 is of unclear clinical significance.

The exercise protocol used in our study was designed to capture VO_2 max and did not demonstrate significant differences in exercise tolerance between treatment groups. As the protocol was designed to capture $\dot{V}O_2$ max, it was likely limited in its ability to detect differences in submaximal exercise tolerance, which are common when hiking or climbing at high altitudes. Future studies may benefit from using a different measure of exercise tolerance that evaluates participants' ability to maintain exercise at levels below the lactate threshold for a longer period.

STUDY LIMITATIONS

This Phase 2 study was limited by the lack of a formal power analysis. The drug was previously tested in a study that had a 36-h ascent to altitude followed by a 1-d stay during which a higher dose and different dosing regimen were used compared with those used in this study. Due to the difference in rate of ascent and dosing regimen, a power analysis was not performed. This lack of power analysis resulted in a trial that was underpowered to detect a difference in efficacy measures based on the results obtained.

A second limitation is that the LLSS, the standard assessment for AMS, is inherently dependent on a participant's subjective interpretation of AMS symptoms. This subjectivity likely resulted in a high degree of variability, which limited our ability to detect meaningful signals in the data with this small sample size. However, we believe that the key limitations of the current Phase 2 study can be addressed by a larger sample size and a simplified dosing regimen using a higher dose of AR36.

Conclusions

Under the current dosing regimens, AR36 did not significantly lower LLSS scores or reduce AMS incidence compared to placebo. AR36 was well tolerated at both dose levels. A larger study with a higher dose is needed to determine whether AR36 could be effective and safe for prevention of AMS.

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Supplemental Materials

Supplementary material associated with this article can be found in the online version at https://doi.org/10.1016/j.wem.2023.09.002.

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ORIGINAL RESEARCH

Exploring the Development of a Canadian Frostbite Care Network and the Future of Frostbite Care in Canada Using a Qualitative Approach

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Introduction—The Canadian Frostbite Collaborative project is exploring frostbite patient care needs and current practices in Canada to inform the development of a Canadian frostbite care network (CFCN) as a national quality improvement initiative.

Methods—Using a quantitative and qualitative approach, this study aimed to define the landscape of current frostbite practices, challenges, and interest in future work.

Results—Current frostbite care practices were initially assessed through semistructured phone interviews of Canadian healthcare providers. Canadian healthcare providers managing frostbite in a range of health disciplines and contexts then participated in focus group sessions discussing the potential roles and opportunities as well as potential challenges in developing a CFCN. Roles and opportunities for a network in advancing frostbite care included facilitating research, educating stakeholders, facilitating collaboration, standardizing care, and advocating for frostbite care. Challenges identified in frostbite care and network development included managing resources, navigating the Canadian healthcare system, overcoming low numbers, and communicating with policymakers and frontline providers.

Conclusions—Formalizing a CFCN may provide important opportunities and support in overcoming critical barriers to providing high-quality frostbite care across Canada.

Keywords: prevention, patient outcomes, protocol, collaborative research, frozen tissue

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Introduction

Frostbite is a thermal injury occurring when tissues are exposed to temperatures below their freezing point for a prolonged period. The severity of frostbite injury is directly related to absolute exposure, including external temperature, wind chill, conditions, and quality of

clothing/tissue protection.[1] The effects of frostbite are exaggerated by alcohol/substance use, tobacco smoking, patient comorbidities, mental illness, use of neuroleptic drugs, previous cold injury, peripheral vascular disease, and neuropathy.[1-8] Approximately 90% of frostbite injuries occur on the hands, feet, or face, highlighting the potential for significant functional implications, particularly in the setting of amputation.

The main principles of frostbite treatment are rapid rewarming in hot water, pain management, and prevention of refreezing.[9,10] Multiple pharmacologic treatment adjuncts have been identified as potentially beneficial in treating frostbite pathophysiology. These include anti-inflammatories, such as ibuprofen and acetylsalicylic acid (ASA); vasodilators, such as iloprost; thrombolytics, such as recombinant tissue plasminogen activator; and the use of hyperbaric oxygen therapy.[2,4,6,10-14] While treatment protocols for managing frostbite have been suggested, evaluation of patient outcomes across institutions is challenging because of low patient numbers and diversity in reporting and patient presentation.[4,5,7,8,10,11] These limitations are well recognized and complicated by demographic/geographic factors that may delay initial treatment and make frostbite difficult to study effectively.[3,4,7] As a result, the management of frostbite is currently quite variable. Available data highlight the need for early intervention by multidisciplinary teams with expertise in the area, including consideration of using a teleconference model.[3,5,15] While there are numerous protocols in the literature,[11,16-18] there is no clear consensus. The Wilderness Medical Society guidelines provide a clear description of the levels of evidence for many treatment modalities.[5] While case evidence for advanced therapies, such as thrombolytics and vasodilators, continues to increase, to move beyond requires consensus, data, and collaboration about how to study optimal management strategies.

Canada is well positioned to be a leader in the treatment of frostbite due to its geographic location. However, studies to date are restricted by small sample sizes, retrospective reviews, case studies, and single-center studies, further compounded by variability in transfer time for patients to receive treatment.[11-13,19,20] The transferability of developed protocols is limited due to lack of clear evidence–based treatments, faculty expertise, availability of medications and equipment, limited overall patient numbers, and equivalency of frostbite severity.[7,11-13] Increased participation in extreme adventure sports combined with the growing epidemic of homelessness will heighten frostbite presentation in both large urban centers and resource-limited rural centers.[1,11] There is an opportunity to improve patient care through the investigation and identification of optimal treatment pathways and practices.

This study aimed to identify and describe current frostbite care practices in both rural and community hospitals and tertiary care burn centers across Canada. The study also aimed to investigate interest in and potential roles of a collaborative Canadian frostbite care network (CFCN) to improve patient outcomes and standardization of frostbite care.

Methods

We have followed the Standards for reporting qualitative research (SRQR) and Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) cohort guidelines, including information in the manuscript on background, survey development, methodology (including sampling rationale), participant description, analytic approach, and discussion (including limitations). We have utilized guidelines for reporting observational studies from the STROBE statement for phone survey analysis and followed the SRQR checklist during manuscript preparation.[21,22]

This study was reviewed and approved by the Laurentian University research ethics board, file number 6020977. In order to answer the research questions, both quantitative (survey methods) and qualitative methodologies (focus group methods) were used. Because of the low number of frostbite presentations, this study used a qualitative approach to target populations with an interest in or experience with frostbite treatment. Incorporating both quantitative and qualitative methods allows enhanced richness of result data and increases the validity and reliability of results.

PHONE SURVEYS

Semistructured interviews were conducted by telephone to collect descriptive data regarding current frostbite care practices and the use of protocols or order sets. Participants were emailed the consent form and survey prior to their interview. Consent was verbally confirmed with each participant prior to data collection. The survey included 20 close-ended questions, several of which invited comments, which were not formally analyzed for thematic interpretation (Appendix A). Survey questions focused on institution demographics, treatments used, the incorporation of frostbite protocols, frostbite grading, technology, access to expertise, barriers to care, and desire to participate in a collaborative frostbite network.

Survey questions were initially developed by the study lead investigator (CC) and vetted through a modified Delphi design with a multidisciplinary national team prior to study commencement. Participation was sought using purposeful sampling, including all Canadian burn centers, as they would be the regional referral sites for frostbite care. Also included were individuals who had previously requested support from the study investigators (AJP or JG) in frostbite case management. Participation was expanded through snowball sampling of interviewees. Phone surveys were conducted by research team members.

FOCUS GROUPS

Focus groups involved in-depth group interviews with targeted participants[23] to identify perceived needs in the management of frostbite. Focus group participants were invited to attend based on their expressed interest in frostbite treatment and were not required to have experience or be experts in managing frostbite. This methodology was chosen as it has been found to be useful for involving care management practitioners with strategy development techniques.[24]

Focus group data were collected in February 2022 via Zoom. The focus group was moderated by a research team member (JS-T) trained in qualitative research methods, with assistance from the entire research group. Initially, in a large group, all participants were introduced to the moderator, the research group, and planned topics to be covered, and consent was confirmed. Participants were then randomly divided into 4 smaller focus groups of 8 to 12 participants (using Zoom breakout rooms), each group with a moderator and note taker.

Moderators guided each focus group using a semistructured script while the assistant made field notes and summarized major discussion points within the web-based chat feature, giving participants an opportunity to clarify anything they felt was missing or misunderstood by the research team. The focus group guide was initially developed through comments collected during the phone interviews. It was then revised for appropriateness in an iterative process, which is standard for qualitative procedures.

Focus group participants were asked to elaborate on topics identified in the semistructured phone interviews, including the roles of a CFCN and how those roles should be prioritized, the challenges and opportunities of implementing a CFCN, and suggestions about research questions in frostbite care that could be facilitated through a CFCN. After each of these topics, the participants were given time to ask questions and voice their opinions. The focus group sessions lasted approximately 1 h and were audio recorded and then transcribed for analyses.

Analysis

Triangulation was used in this study (using phone surveys and focus groups) to enhance the richness of the data and increase the validity and reliability of results.[25]

PHONE SURVEYS

Quantitative responses were collated and analyzed using Microsoft Excel (2022). Data analyses included descriptive statistics. Missing data were not imputed. Comments gathered from participants were transcribed, and the most common responses were used to inform the focus groups' direction.

FOCUS GROUPS

Focus group qualitative content was analyzed using Braun and Clarke's[26] (2006) 6-step thematic analysis. Four authors independently analyzed transcript data from 3 of 7 focus group transcripts using NVivo software to inductively identify preliminary codes. They then met to discuss emerging codes and agree upon a code book. All focus group transcripts were then analyzed by 2 reviewers using the developed codes to iteratively finalize themes. Researchers performing coding communicated as needed during final coding to discuss any new codes that emerged. Saturation of data[26] was ensured during the coding process. The authors focused on establishing trustworthiness at each phase of the thematic analysis.[27] Appendix B highlights the components of trustworthiness of qualitative data.[28]

Results

PHONE SURVEYS

Phone surveys were primarily conducted between March and August of 2021, with 2 surveys taking place in early 2022 (Appendix A). In total, 21 healthcare professionals from throughout Canada participated, with representation from all provinces and territories except Prince Edward Island, New Brunswick, and Newfoundland and Labrador. Participants included 12 physicians, 1 nurse practitioner, and 8 hospital pharmacists. There were 14 participants from tertiary care facilities and 7 from rural

or community hospitals. All specialty burn units in Canada were invited to participate in this survey, and 11 of them contributed. The participants' precise specialty/area of practice, geographic location, and employment institution are not detailed to preserve participants' anonymity.

Thirty percent of respondents indicated that their facility treats <5 frostbite cases, while 40% routinely see >10 cases over a 5-y period. Equal numbers of facilities reported having a frostbite order set (48%), and 57% use a formal grading system (most often the Cauchy system).[22] Only 20% of respondents indicated using nuclear imaging or angiography.

Only 38% of respondents indicated that their facility has a treatment protocol for frostbite, 75% of whom use the Whitehorse protocol. Barriers for treatment included obtaining and administering iloprost, which requires special authorization from Health Canada. Low patient volume and lack of experience/expertise and specific resources were also reported.

Rapid rewarming protocols were used by 53% of respondents, with a median temperature of 39°C, ranging from 37 to 40°C. Nonsteroidal anti-inflammatory drugs were used by 95% of facilities surveyed, most commonly ibuprofen (90%), followed by ASA and ketorolac. Other forms of pain management were used by 86% of facilities, most frequently opioids (95%). Topical medications were used by 81%, most frequently Aloe vera (58%), followed by silver-based products (20%). Prophylactic antibiotics were used in only 14% of responding facilities.

Seventy-one percent of respondents indicated that their facility used either vasodilators or thrombolytic agents, with iloprost reported slightly more often than alteplase (52% vs 43%, respectively). Anticoagulants were used in combination with these medications in 47% of these facilities. While 38% of respondents indicated having access to hyperbaric oxygen, many commented that it was not regularly used in frostbite care.

With respect to access to local expertise in frostbite care, respondents confirmed that 50% had access to (or were themselves) local experts, while 71% had access to expertise via email, text, or telephone. Respondents almost unanimously agreed that there is a need for improvement in frostbite care (94%), and 100% of respondents supported standardization of treatment protocols. A significant number of respondents (90%) indicated that they were willing to participate in a national collaborative frostbite care network, highlighting the need for research on the most effective protocols, sharing of best practices, and patient care.

Participants unanimously indicated that standardization of evidence-based protocols would significantly improve treatment of patients with frostbite, and >90% were interested in participating in a CFCN.

FOCUS GROUPS

Forty-three participants took part in the virtual focus group and were randomly divided into 1 of 4 smaller groups after introduction, consent was obtained, and preliminary information was shared. Participants varied by stakeholder group, sex, and location of residence across Canada. Participants were asked their employment details, but not all chose to disclose this information. Responses of the remaining participants are not reported to avoid inadvertent identification of participants. See Tables 1 and 2 for details on stakeholder groups. Focus group discussion focused on the roles, priorities, challenges, and opportunities of a CFCN (see Table 3 for focus group script).

Roles and Priorities of a CFCN

After discussing the possible roles and priorities of a CFCN, 5 main categories emerged. Top roles and priorities included 1) facilitating research, 2) educating stakeholders, 3) facilitating collaboration, 4) optimizing frostbite care, and 5) advocating for frostbite care in Canada. See Appendices C and D for complete quotations for each category.

FACILITATING RESEARCH

Participants felt that a network could facilitate conducting research and data collection. Primary proposed roles of this network included developing specific research questions, facilitating multicenter studies, and sharing data through a central registry.

> *"I think we have an advantage if we have a network that can study protocols…across multicenters, and have larger numbers, and maybe try to hammer down at least what is our current best practice, because I think there is no good standard right now that is across the board as the all-encompassing standard to follow."* (Transcript 2)

Table 1. Respondents: phone surveys

	Number (total N=22)	*Percentage (%)*
Physician	10	55.6
Hospital pharmacist	8	44.4

Table 2. Stakeholder groups: focus groups

Stakeholder group	*Number (total N=43)*	*Percentage (%)*
Physician	19	44
Hospital pharmacist	3	7
Medical student	2	5
Medical technician	2	5
Search and rescue technician	2	5
Emergency medical response (ski patroller)	1	2
Registered nurse	1	2
Physician assistant	1	2
Engineer	1	2
Primary care paramedic	1	2
High school outdoor education teacher	1	2
Did not specify	9	21

EDUCATING STAKEHOLDERS

Educating stakeholders was another commonly cited role for a CFCN. Separate discussions emerged on the need to educate healthcare professionals and the public. The primary educational needs expressed for health professionals were related to assessment and management, whereas prevention was the primary educational need expressed for public stakeholders.

> *"Finding a way to get everybody aware of all these new protocols, and all the advances in this field, and probably afterwards getting more education for nurses, and primary care."* (Transcript 4)

FACILITATING COLLABORATION

Another important role that emerged during focus group discussions was the ability of a network to facilitate collaboration. Specifically, facilitating interdisciplinary and national or multicenter collaborations was described as a role the CFCN could take on to benefit stakeholders. Sharing knowledge within such a group was stressed, and development of a forum for case study discussion was suggested.

> *"I think it is super good to [have] a multidisciplinary approach. I think that…a lot of the standards of care come at the hospital setting, but I think it is really important that this task force is really broadly distributed so it includes everyone at the point of care…like paramedics when they are picking them [patients] up, the nursing staff who are assessing them right away, and all the hospital staff as well. So, I think regardless of what goals are going to be worked on right away, I think it is important to develop the network with a lot of stakeholders from different areas across care."* (Transcript 2)

Table 3. Focus group interview guide

1. What are the possible roles of a Canadian frostbite care network?
2. How could these roles be prioritized? What is most important to start with?
3. What challenges currently exist to implementing a care network?
4. What opportunities would a care network create?
5. What specific research questions in frostbite care could be facilitated through a national network?
6. What are the next steps for formalizing a Canadian frostbite care network?

OPTIMIZING FROSTBITE CARE

The need for a network to optimize care was a central theme in many discussions. The method of optimizing care came forward when participants described CFCN's potential role in developing protocols and supporting protocol implementation. Participants described both roles as being necessary at all stages of the treatment trajectory from prehospital to inpatient and outpatient care, inclusive of quality improvement to optimize patient care.

> *"A protocol that has a few different streams that people can provide treatment through. So, for example, if you are in an institution that doesn't have iloprost or TPA yet, or maybe you are just in a very small rural community health center, what you can do to provide optimal care with limited resources."* (Transcript 5)

ADVOCATING FOR FROSTBITE CARE IN CANADA

Finally, participants described advocacy as an important role of a CFCN. This included the need to advocate for resources related to frostbite assessment and management, such as imaging, medications, and clinical expertise. Participants commented that advocacy should occur through communication with stakeholders and by demonstrating leadership in frostbite care.

> *"…let us create a network, create the governance, create some guidelines, communications, a website…[we need to get] a bit more public…a bit more into their face, and then we start presenting in different areas, so at any national meetings, we go there…And, then we need to start networking and going and beating our drums to other societies, or anywhere else where we think that it may have an impact…and we make alliances from there."* (Transcript 3)

Challenges of Implementing a CFCN

When considering the challenges of implementing a CFCN, 4 main themes emerged. These included 1) managing resources, 2) navigating the Canadian healthcare system, 3) overcoming low case volumes, and 4) communicating effectively with stakeholders. See Appendix B for example quotes for each theme.

MANAGING RESOURCES

Managing resources was frequently reported as a challenge in implementing a CFCN. This was primarily described in relation to time constraints and human resources, in addition to logistical planning for a platform, technology, database creation, and overall funding. The need for identified champions in the field was of particular importance.

> *"Certainly…getting a local champion is always a challenge, especially in places where there is quite a lot of [turnover] and there is so much going on. Everyone is so short staffed, so finding a local champion of each disease state is certainly a challenge locally."* (Transcript 4)

NAVIGATING THE CANADIAN HEALTHCARE SYSTEM

Participants described navigating the Canadian healthcare system as a challenge to the implementation of a CFCN. Differences in healthcare across provincial and territorial boundaries and regional variation, such as urban vs rural settings, need to be considered for a meaningful national collaboration.

> *"…Some of the challenges in Canada are that we talk about equal access to healthcare, but it isn't equal access to healthcare if you are in a remote area that doesn't have some of the iloprost, or the TPA even, or access to some of the warming. So, I think that is a challenge that we do need to take into consideration for implementing the network, is the different levels of access to the different resources, and maybe an understanding of how to implement some of these suggestions, or some of these opportunities as we go through that."* (Transcript 1)

OVERCOMING LOW CASE VOLUMES

The low number of frostbite cases and resulting reduced exposure and expertise in frostbite may present a challenge when implementing a successful CFCN.

> *"The other thing is I think with frostbite, it is temporary, right, it is 5 months of the year, not the other 6…I think the challenge is one it is seasonal…We don't have a story that we can say that is compelling and that politicians up in the parliament take notice of. And, it is low incidence so people when they put in their list of 100 things, I don't think it will come in the top unless we make noise of it."* (Transcript 3)

COMMUNICATING EFFECTIVELY WITH STAKEHOLDERS

Finally, effective communication was said to be a challenge facing a CFCN. This came forward when discussing the need to engage policymakers and frontline care providers. While local practitioners may see the need for these resources, there is a requirement for provincial and national support to ensure that meaningful change can occur.

> *"Ultimately, the patient presents to the emergency room, and if the person who sees them, or the family doctor, doesn't recognize that, A: this has a specific way of caring for it, and there is expertise in our center for this, there are policies, there is a care network around it, we may never be involved with that patient's care, even if we are in town working in a nearby location. I feel like there is a lot of education that would be needed… creating the network and [getting] people who are aware of the network, whether or not they are involved intimately with the network...these are 2 interdependent challenges."* (Transcript 3)

Interpretation

Quantitative data collected through phone surveys confirmed that frostbite treatment across healthcare centers within Canada varies significantly with respect to available resources, treatments, and expertise. While many institutions make every effort to optimize patient outcomes, lack of standardized protocols, evidence-based guidelines, and resources result in inconsistency in patient care.

Perhaps more important, respondents from both the phone survey and focus group confirmed that there is significant interest, commitment, and need for scientific data collection and analyses to establish optimal protocols for patients in rural and urban settings. It has been noted in publications prior to this study and from respondents in this study that current evidence is weak due to low patient numbers and predominance of retrospective single-center studies.

While the data collected offer a "snapshot" of current frostbite care throughout almost all of Canada, they do not represent all healthcare centers and were potentially biased by including participants with interest in frostbite care.

What was consistently reported from both the semi-structured interviews and the focus groups is the need for a CFCN to facilitate research, educate stakeholders, facilitate collaboration, optimize frostbite care, and advocate for frostbite care in Canada.

Creating this CFCN would help define and address existing gaps in frostbite literature to improve frostbite care and outcomes. A CFCN could provide a critical opportunity to better understand the care needs of patients and variability in frostbite care through collection and analysis of data, treatment pathways, and patient outcomes across Canada. A critical goal of this network would also be to support development of evidence-based best practices to optimize care. A CFCN could enable data collection across multiple centers to increase patient population samples and support advocacy for improving frostbite care in Canada. The presentation of similar infrequent conditions that occur across vast geographic areas would likely benefit from discussion among interested clinicians and researchers to create a registry that can be used to develop, standardize, and optimize protocols and treatments for frostbite.

Challenges in creating a CFCN were noted and primarily involve human resources, navigating the various provincial healthcare systems, overcoming low case numbers, and communication. While these challenges exist, participants demonstrated significant interest and stressed the need for improved patient outcomes through clear and consistent treatment pathways.

Future directions include developing a platform for the CFCN and beginning to implement the roles and priorities identified in this study. Identifying local champions and fostering leadership in frostbite care research and practice are also priorities for the CFCN to optimize its potential. By doing so, multicenter research projects on frostbite presentation and outcomes across regions and demographics can be supported while laying the groundwork for clinical trials and development of evidence-based protocols.

Limitations

To preserve participant anonymity, granular demographic information on participant location and occupation was not reported for either the phone survey or focus groups. This limited our ability to ascertain participants' level of experience with frostbite and their understanding of current management practices. Potential phone survey participants were identified by contacting Canadian burn centers, individuals who had previously requested help with frostbite management, and snowball sampling from interviewees. This may have resulted in selection bias as all participants would have had some interest in frostbite management. It may also have resulted in sampling bias as it does not reflect the experiences of physicians who may treat frostbite but who are unaffiliated with burn centers and have not discussed management with others, for example, rural or remote physicians unaffiliated with academic centers.

Conclusion

Frostbite care varies across Canadian centers due to availability of resources, expertise, and low patient numbers. The participants in this study expressed a need for standardized and evidence-based protocols that can be used within an institution's available resources to provide optimal patient care. There is a clear need and keen interest in collaborative research, education, and communication among Canadian healthcare providers to facilitate quality improvement in the future of frostbite care.

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Supplemental Material(s)

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ORIGINAL RESEARCH

Performance of a Chemical Heat Blanket in Dry, Damp, and Wet Conditions Inside a Mountain Rescue Hypothermia Wrap

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Introduction—Casualties with accidental hypothermia are evacuated using multilayer wraps, typically including a chemical heat blanket (CHB), a vapor barrier, and an insulating outer bag. We investigated CHB performance against dry, damp, and wet fabric, in a multilayer wrap, in response to a case report indicating diminished performance when wet.

Methods—We wrapped a torso manikin in a base layer, CHB, vapor barrier, casualty bag, and vacuum mattress, recording CHB panel temperatures at intervals of up to 7 h. Experimental conditions were dry, damp, and wet clothing, with 2 blankets tested in each condition. We subsequently used a forward-looking infrared camera to assess whether the panels heated evenly and heat flux sensors to quantify heat transfer across 2 dry, 1 damp, and 1 wet fleece under CHB panels.

Results—Chemical heat blankets maintained heat output for >7 h inside the wraps. Median (IQR) panel steady state temperatures were 52°C (39–56°C) against dry fleece, 41°C (36–45°C) against damp fleece, and 30°C (29–33°C) against wet fleece. Peak panel temperature was 67°C. The heat flux results indicated that CHBs generated similar quantities of heat in dry and damp conditions, as the lower temperatures were compensated by more efficient transfer of heat across the moist clothing layer. Chemical heat blanket heat output was diminished in wet conditions.

Conclusions—Rescuers should cut off saturated clothing in a protected environment before wrapping casualties, but damp clothing need not be removed. Because of the high peak temperatures recorded on the surfaces of CHBs, they should not be placed directly against skin, and compression straps should not be placed directly over CHBs.

Keywords: resuscitation, cold injury, emergency responders, emergency shelter, transportation of patients, equipment design

Introduction

Accidental hypothermia is defined as an involuntary drop in core temperature to below 35°C.[1] Mountain rescue teams (MRTs) are often called on to assess and treat casualties in cold and wet environmental conditions. The Mountain Rescue England and Wales database recorded that 169 of 4225 (4 %) casualties were hypothermic in the years 2019 through 2021, while a study from Scottish Mountain Rescue identified 46 of 333 (14 %) casualties suffering from the effects of cold or exhaustion.[2] International guidelines have been published to assist MRTs in assessing and managing casualties with hypothermia.[3,4] These recommend that casualties with a core temperature of <32°C and those who require stretcher evacuation should be placed in a multilayer wrapping system to provide insulation and protection from the environment.[1,3]

Various materials and systems have been studied to determine the optimum composition for a hypothermia wrap.[5] Mountain Rescue England and Wales teams use a wrap consisting of a chemical heat blanket (CHB) applied on top of a casualty's base layer, then a vapor barrier,

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surrounded by an insulating fiber pile bag with a wind and waterproof outer layer. The wrapped casualty is supported in a vacuum mattress, which provides additional insulation and mechanical stability for injuries and aids careful moving and handling.[6] Chemical heat blankets have been shown to produce about 300 kJ of heat and reliably deliver this over several hours.[7] In mildly hypothermic, shivering casualties, exogenous heat will attenuate shivering heat production equal to the amount of heat donated. However, the addition of heat may still be of net benefit in increasing comfort and conserving body energy stores. Adding endogenous heat may decrease pain, cardiac work, and oxygen consumption in injured or sick casualties.[8] In nonshivering casualties or those in whom shivering is reduced due to age, trauma, or depleted oxygen or energy supplies, the provision of exogenous heat may reduce the depth and duration of the afterdrop and increase rate of rewarming (depending on the energy stores).[8-10] A case report described the use of a CHB to successfully rewarm a hypothermic patient in the mountains.[11] However, the authors reported a failure of some panels of their CHB. It was unclear from the report whether they attributed this to premature exposure to oxygen or being unprotected from the rain, but they stated that "the CHB will not work when wet." In a mountain rescue environment, it may not be desirable or even possible to completely remove clothing or dry a casualty prior to wrapping. There is also a case report of burn injuries from heat pads in the treatment of hypothermia.[12] Finally, the manufacturer's instructions are to open the CHB to the air and allow 15 min to reach operating temperature. It is therefore common practice for MRTs to open the CHB and leave it loose on the top of a rucksack before arriving at the casualty, but it is unknown whether this compromises performance of the CHB. The questions of how well CHBs work against wet fabric and when opened early are of practical significance to rescue teams. In this series of experiments, we measured the performance of the Ready-Heat II CHB torso-only version (TechTrade LLC, Orlando, FL) against dry, damp, and wet fabric. The Ready-Heat II CHB is used by several MRTs in the UK. The blanket contains 6 independent panels arranged in a grid. Each panel contains a 10 cm × 13 cm sachet activated by exposure to atmospheric oxygen, releasing heat via an exothermic reaction. The panels are protected on their exterior ("non−patient-facing") surface by a water-resistant membrane built into the blanket.

Our first study investigated the performance of the CHB in a wrap. We then undertook bench tests to address specific questions arising from that experiment. These were 1) whether the panels heated evenly, and if so, whether the single point measures of temperature in the wrap experiments were representative of overall panel temperatures, and 2) whether the panels were generating different amounts of heat in each condition or whether they were working equally well, but the heat was being transferred to the water in the clothing.

Methods

We used a torso manikin (Little Anne, Laerdal, Stavanger, Norway) to provide the surface area and volume of a patient (Figure 1). We clothed the manikin in a base layer (Pamenta T, Paramo, Wadhurst, UK) and then wrapped it in a CHB. We zipped a midweight polyester fleece (Keela, Fife, UK) and a waterproof jacket (Gore-Tex, Sprayway Equipment, Hyde, UK) over the CHB. Then, we wrapped the dressed manikin in a vapor barrier (Blizzard AMB Trauma Blanket, Blizzard Survival, Bethesda, North Wales, UK), a fiber pile casualty bag (Mountain Equipment, Hyde, UK), and a vacuum mattress (Aiguille, Kendal, UK). We sealed the vapor barrier at the feet and head using the drawcord. We minimized the dead space by rolling the blanket on itself. We closed the fiber pile bag using the drawcord around the head.

We shook the blankets to expose them to the open air according to the manufacturer's instructions. We left 2 in the open air as controls, while those that went into the wraps were kept loosely in a rucksack for 30 min to simulate mountain rescue practice. The controls were to clarify whether being placed in a rucksack made the CHB faster or slower to activate and whether the wrap might ultimately suffocate the panels. We recorded temperatures intermittently with a digital industrial thermometer (Signstek 6802 II) and K-type thermocouple (accurate to 0.1°C) attached to the centers of the "patient-facing" sides of each of the 6 CHB panels. We took measurements at 15-min intervals for 3 h and then at 30-min intervals for up to 7 h without opening the wraps. The 3 experimental conditions were 1) dry, 2) damp (clothes soaked in 15°C water and then centrifuged for 2 min at 400 RPM), and 3) wet (clothes soaked in 15°C water and held vertically for 2 min to allow excess water to drip away).

In subsequent bench tests, we positioned a thermal camera (A320, FLIR Systems UK, West Malling, UK) above the non−patient-facing side of a CHB to assess distribution of heat generation across a panel (Figure 2). We attached combined thermistor and heat flux sensors (Concept Engineering, Old Saybrook, CT) to the center of the "patient-facing" side of the panels, resting on a single 100% polyester fleece layer (Primark, Madrid,

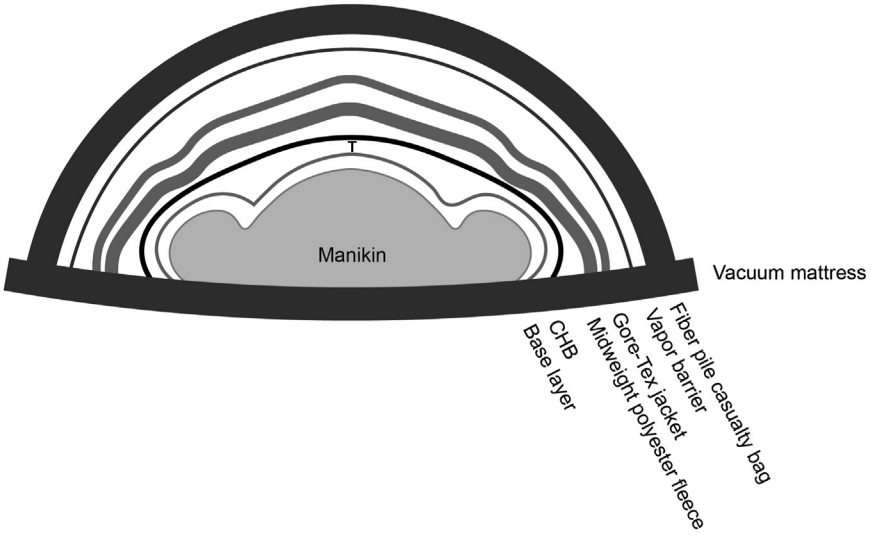

Figure 1. Experimental setup for hypothermia wrap. T indicates the temperature sensor position; CHB, chemical heat blanket.

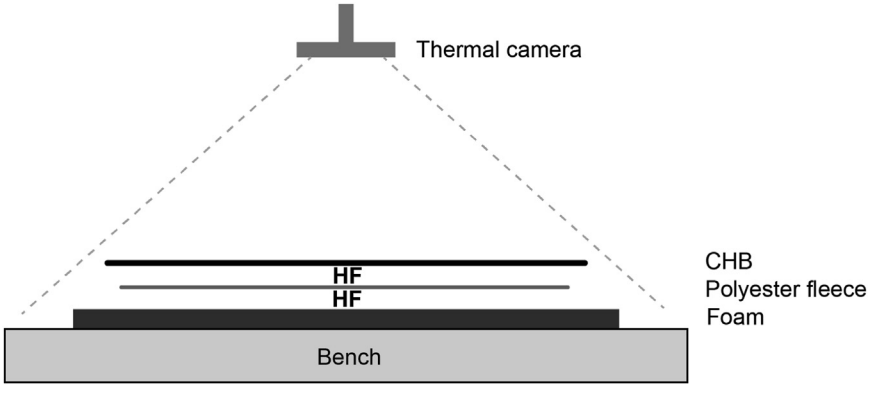

Figure 2. Experimental setup for bench tests. HF indicates the heat flux sensor position; CHB, chemical heat blanket.

Spain), with a second heat flux thermistor under the fleece, all on top of an insulating foam base. Heat flux thermistors measure the rate at which heat is transferred per unit area, per unit time, in addition to temperature. The resolution of the heat flux component of these sensors was ~150 $W/m^2/mV$. We connected the thermistors to a Squirrel Temperature Data Logger (Omni Instruments, Dundee, UK), recording temperatures every minute. We tested 2 panels side by side in 2 experiments. In both experiments, the left panel was against dry fleece. In the first experiment, the right panel was against damp fleece (dampened with 0.02 g/cm^3 of 15°C water), and in the second experiment, it was against wet fleece (soaked with 0.2 g/cm^{-3} of 15°C water).

We conducted all the tests indoors in ambient air temperatures of 17 to 21°C (wrap testing) and 17 to 19°C (bench testing). We defined steady state as a variation in temperature of <1°C over a 30-min period. We analyzed the results using R Studio (v1.0.143, R Core Development Team v3.4.1) and assessed them using descriptive methods (skewness, outliers, and distribution plots) and inferential statistics (Shapiro-Wilk test). We reported nonparametric results as median (IQR).

Results

The blankets left in the open air warmed more slowly than those in the rucksack. At 30 min, before being placed in the wrap, the panels in the rucksack were 43°C (38–49°C), compared to 32°C (30–34°C) in the open air (Figure 3). Once in the wrap, the panels generated the

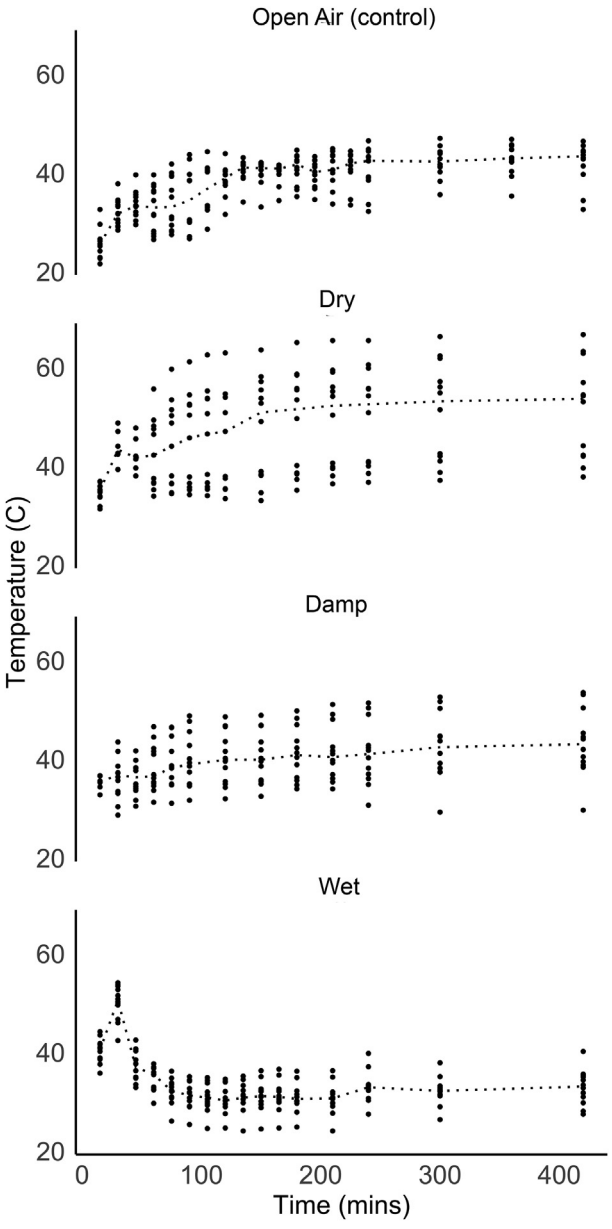

Figure 3. Panel temperatures recorded during the hypothermia wrap experiments. Points indicate individual panel temperatures; dotted lines indicate median temperatures.

highest temperatures when placed against dry fleece (52°C [39–56°C]) at steady state. The highest single temperature recorded directly against a panel was 67°C. There was also the greatest variation among panel temperatures when against dry fleece. Panel temperatures were lower against damp fleece (41°C [36–45°C]) and lowest against wet fleece (30°C [29–33°C]), with reduced variation among panel temperatures. The time to reach steady state was longer against dry and damp fleece than against wet fleece (median, 180 vs 120 min). Steady state temperatures were maintained until the end of the experiment (7 h) in all conditions.

In the bench testing, we recorded temperatures and heat flux from 2 panels side by side. The left panel was laid against dry fleece and the right against damp fleece and then wet fleece. The thermal camera demonstrated that the panels emitted heat most vigorously from the areas where the volume of reactive powder was greatest, generally at the centers but with some variation across the panel surfaces. Panel temperatures were higher against dry (53°C and 48°C) rather than damp (42°C) or wet (32°C) fleece at steady state. The temperatures under the fleece (analogous to the patient's skin) were lower than those measured directly against the panel but followed similar trends (dry, 46°C and 38°C; damp, 41°C; and wet, 31°C). The difference between the temperatures against the panel and underneath the fleece was greatest with dry fleece and least with wet fleece. Heat flux from the panels was highest when they were placed against dry fleece and lowest against wet fleece (Figure 4). The dry fleece conducted the lowest proportion of heat from the panels to the sensor underneath the fleece (47% and 39%), compared to that for damp (65%) and wet (59%) fleece.

Discussion

The panels reached higher temperatures faster when kept in a rucksack than in the open air. However, the heat flux results demonstrated that heat is transferred to a patient from the moment of panel activation. Application of a CHB should not be delayed if there is no opportunity to open it early. The CHBs in our simulations lasted for at least 7 h, implying that rescuers would not need to consider checking or changing them before 7 h. It is not necessary to open the wrap to let in more oxygen. Steady state temperatures in the dry wrap were higher than those in the open air, presumably because of the added insulation.

Many casualties in the British mountains have damp or wet clothing. The heat flux results indicated that the panels performed equally well in dry and damp conditions. We recorded lower temperatures when the panels were placed against damp clothing, but the moisture increased the efficiency of heat transfer to the layers below, so the amount of heat transferred through the clothing was comparable. The scenario of very wet clothing, saturated with water, is a worst-case situation in the mountains or might represent a person rescued from the water. When we opened our wrap in the wet

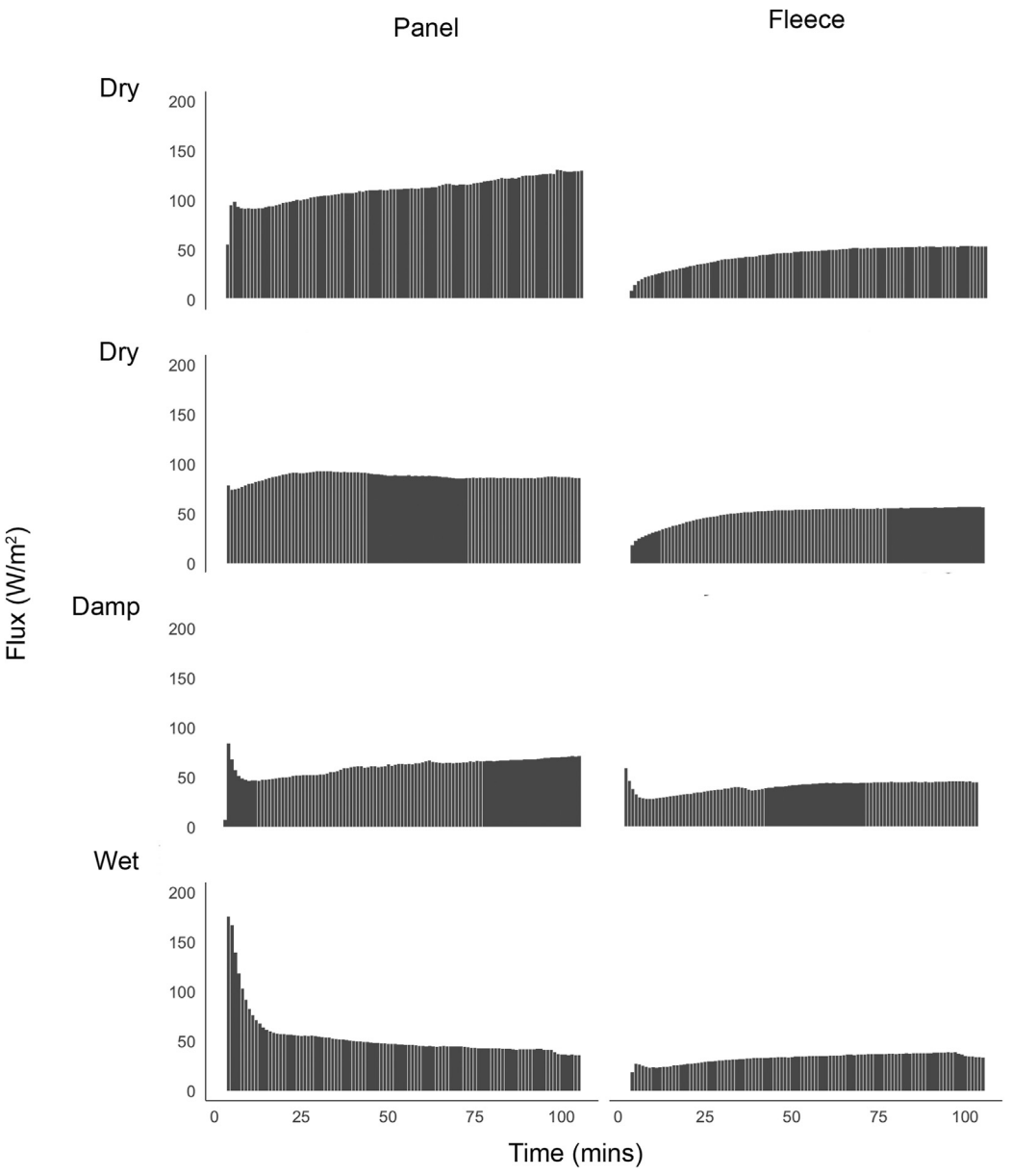

Figure 4. Heat fluxes recorded during the bench testing.

condition, the manikin was lying in a pool of water, and the clothing was still saturated. The CHBs were warm to touch, and the material was wet. Heat flux results indicated diminished panel performance in the wet condition, not simply lower temperatures because of increased heat transfer to the water. We think that a very wet environment caused water to surround the panels, compromising the chemical reaction and decreasing heat production. However, none of the individual panels failed, in contrast to the case report cited in the introduction. We recommend that damp clothing be left on a casualty, as removing the clothing might risk further cold exposure, and the damp clothing will not compromise heat production from a CHB. We recommend that rescuers cut off saturated clothing before wrapping a casualty. At the incident site, an emergency shelter to protect the casualty and the CHB would assist with this maneuver.

Because of the high temperatures measured at the surface of the CHBs when used against dry fleece, CHBs should not be placed directly against the skin. The dry

fleece conditions also had the biggest variations in temperature, possibly because the addition of water helped distribute the heat more evenly in the other 2 conditions. Risk of skin injury is determined by the intensity and duration of the heat applied. The earliest perception of pain occurs just above 43°C in adults, while burn injury, defined as irreversible necrosis of the dermal surface, occurs when the temperature at the junction of the dermis and epidermis exceeds 44°C.[13] Compression increases heat transfer by improving the contact interface between the surfaces.[14] The peak temperatures measured in the experiments (67°C against a panel; 46°C under a dry fleece) suggest that rescuers should continue to place a layer between the CHB and the skin and should avoid tight compression strapping directly over a CHB, especially in unconscious casualties or those who cannot complain of pain.

Next steps would include accounting for the thermal properties of the human body using a thermal manikin and testing various models of blankets under a variety of environmental conditions.

LIMITATIONS

We examined the performance of one specific model of CHB, so our results cannot be generalized to other products. Because of experimental constraints, the wrap and bench tests were performed on separate occasions at separate locations, with thermocouples used in the wrap experiments and thermistors used in the bench experiments. It was also not possible to instrument both sides of the clothing in the wrap, which would have given a clearer indication of temperatures against a casualty's skin. Both thermometers made "point measures" of approximately 1 cm^2 of panel surfaces. It was an assumption that the point measures were representative of the temperatures produced across the whole panel, and the model could not represent temperatures during the exothermic reaction. The wrap model also did not isolate or control for the availability of atmospheric oxygen. We conducted the experiments in warm, still conditions, rather than the cold, windy scenarios where CHBs are typically employed. The bench testing setup and the torso manikin did not conduct, circulate, produce, or store heat in the same manner as a human body. Therefore, the model could not represent how heat generated by a CHB would be distributed to a patient.

Conclusions

Opening the CHB before reaching the casualty and enclosing it in a rucksack did not compromise the activation of the panels. Rescuers can expect performance to be maintained for 7 h without opening the wrap. We recommend that rescuers cut off saturated clothing in a protected environment before wrapping the casualty, but damp clothing need not be removed. Our finding of high peak panel temperatures suggests that CHBs should not be placed directly against the skin and that rescuers should avoid tight compression straps directly over CHBs.

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Author Contributions: study concept and design (MG, GL, KG, MW); data acquisition (MG, GL, KG, MW); data analysis (MG, MW); drafting of the manuscript (MG, MW); revision and approval of final manuscript (MG, GL, KG, MW).

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CASE REPORT

Stress Fractures of the Distal Phalanx in Skeletally Immature Sport Climbers

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Stress fractures in the distal phalanx of skeletally immature patients are rare and previously unreported clinical occurrences. We report on 2 adolescent sport climbers with such fractures of the dorsal metaphysis of the distal phalanx at the point where parts of the extensor tendon insert. A conservative treatment approach alone was sufficient in healing this fracture type in both patients after 12 wk. Clinicians should be informed of the existence of this rare clinical phenomenon and counsel patients that a conservative treatment approach may result in complete healing without the need for an invasive procedure.

Keywords: hand trauma, pediatric, extensor tendon insertion, grip position, distal interphalangeal, treatment

Introduction

Distal phalanx fractures are the most common fractures of the hand in both adults and children.[1] Typical fracture patterns have been described for the adult as well as the growing phalanges.[2,3] Even though stress fractures are the most common finger injuries among adolescent sport climbers, these lesions typically present as epiphyseal stress fractures at the base of the middle phalanges but have not previously been described in the distal phalanges.[4-6]

We report on 2 cases of chronic fractures in the distal phalanx presenting as stress fractures of the dorsal metaphysis. Further analysis of these specific cases allows for conclusions about the expansion of the insertion points in the extensor tendons of the growing hand.

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Case Report

CASE 1

A 13-y-old male rock climber presented to the Hand Clinic with a 3-mo history of progressive pain localized to the distal interphalangeal (DIP) joint of the right ring finger. Specifically, he noted that the pain was worst while using an "open grip position" during rock climbing. In this position, the DIP joint is flexed and the proximal interphalangeal (PIP) joint is almost entirely extended. The patient denied any acute trauma in the affected area. Upon clinical examination, the patient demonstrated a normal range of motion, but pain/tenderness was noted when the DIP joint was passively extended. Standard radiographs in the lateral view of the hand were diagnostic for a fracture of the dorsal metaphysis of the distal phalanx without articular involvement (Figure 1a and b). Furthermore, an ultrasound examination revealed that a small hyperechogenic fragment was visible without further displacement (Figure 1c).

Case 2

Our second patient, a male indoor sport climber, presented to the Hand Clinic at the age of 15 y after several weeks of progressive pain in the dorsal aspect of the distal phalanx of his right middle finger while actively

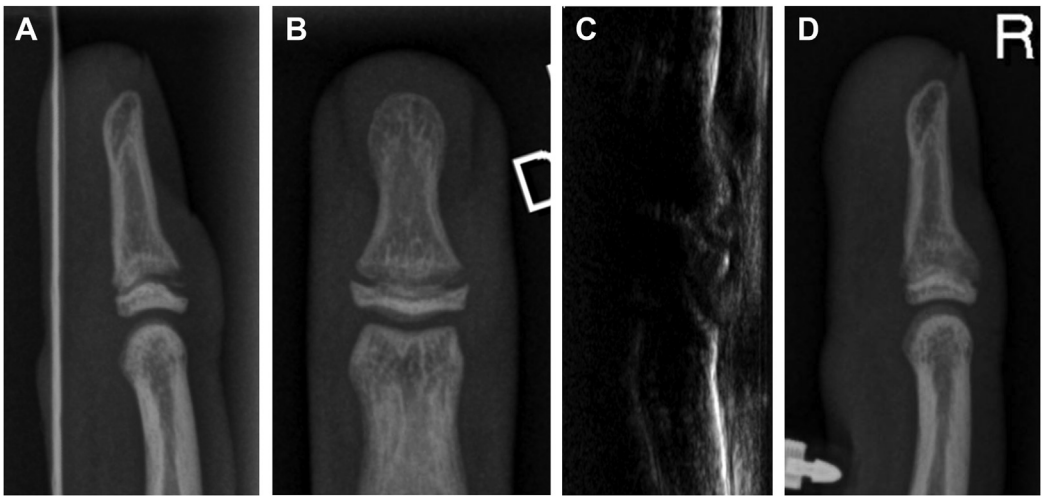

Figure 1. A and B, Radiographs of the distal phalanx of the right ring finger. C, Ultrasound image of the dorsal aspect of the right ring finger's distal interphalangeal joint. D, Radiographic consolidation of the right ring finger after 3 mo.

flexing or passively extending the DIP joint. As with the previous patient, acute trauma was not reported, and the physical examination revealed a full range of motion with notable pain/tenderness over the dorsal aspect of the DIP joint. Similarly, radiographs in the lateral view demonstrated a fracture of the dorsal metaphysis without articular involvement (Figure 2).

TREATMENT

In both patients, a conservative treatment protocol was prescribed: a reduction in load-bearing activities of the finger and avoidance of terminal joint mobilization by taping of the DIP joint. A planned follow-up visit was scheduled for 12 wk after the initial consultation.

OUTCOME

Both patients complied with the treatment protocol as instructed, and neither required any interim consultations or interventions between the initial consultation and planned follow-up. At 12 wk, both patients reported resolution of their symptoms, and complete consolidation was noted on radiographs (Figures 1d and 2c).

Discussion

Stress fractures due to overuse in young athletes have been widely described in various sports.[7] Specifically, among skeletally immature climbers, the dorsal aspect of the middle phalanx base is prone to epiphyseal fractures (Salter-Harris type III fractures).[8,9] These fractures are explained by an overuse of the "crimp grip position," wherein the PIP joints are fully flexed and DIP joints are hyperextended. This results in high compressive forces on the dorsal aspect of the epiphysis and growth plate, which leads to the aforementioned fractures (Figure 3a).[10]

In contrast, the "open grip position," wherein the DIP joint is flexed and the PIP joint is (nearly) fully extended (Figure 3b), leads to a different force distribution in the fingers. In this state, major tension forces are applied to the distal phalanx. A stress fracture occurs when repetitive tension stress exceeds the strength of the phalanx, causing a small part of the bone attached to a tendon or ligament to tear away from the central part of the bone.[11] Hence, when examining the case examples described here, relative to the distal phalanx, it is reasonable to conclude that a portion of the distal extensor digitorum communis tendon must attach to the proximal rim of the metaphysis of the distal phalanx.

Although it has been previously described that the extensor digitorum communis tendons insert into the distal phalangeal epiphyses of their respective rays, our ultrasound examinations in children show an additional metaphyseal insertion of the extensor tendon (Figure 4).[12]

This configuration also aligns with the findings of Hoch et al,[13] who demonstrated through plastination histologic cross-sections of the fingers that a part of the extensor tendon indeed inserts into the proximal part of the diaphysis (Figure 5).[14] We believe that this anatomic configuration resembles that which is found in the ulnar and radial collateral ligaments that extend beyond the edge of the physis to integrate the periosteum of the distal phalanx, as detailed by Bogumill[15] and verified via histologic sections.

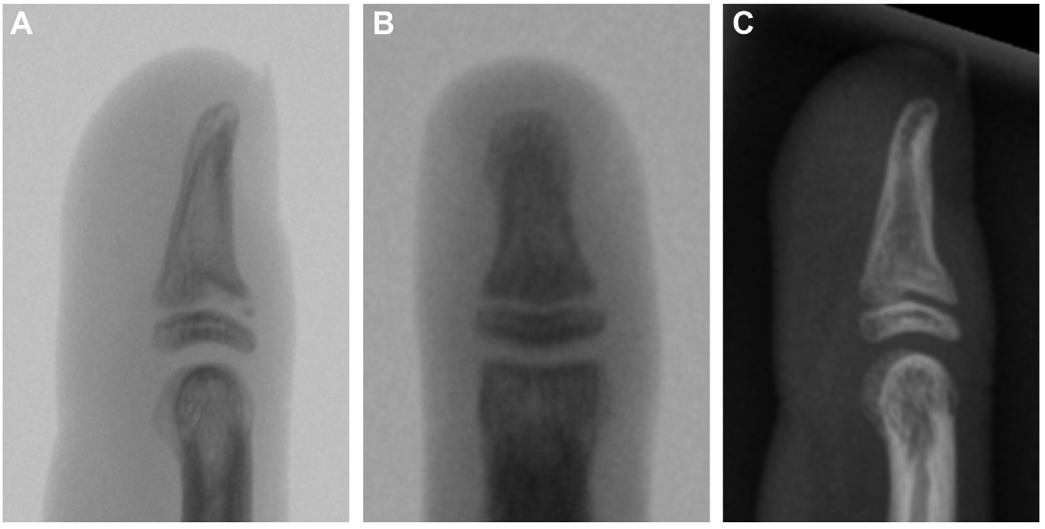

Figure 2. A and B, Radiographs of the distal phalanx of the right middle finger. C, Radiographic consolidation of the right middle finger after 3 mo.

The constellation of presenting symptoms and objective findings in the cases discussed herein represent a distinct type of injury. First, this fracture type appears to result from a highly specific overuse, namely, the "open grip position" in sport climbing. Second, this fracture type is specific to skeletally immature patients. Fusion of the epiphysis in the distal phalanges of the hand typically begins at the age of 12 y in girls and occurs between the ages of 13 and 17 y in boys.[16] Consequently, in skeletally immature patients, the metaphyseal area is less stable and more susceptible to chronic stress and microfractures. The resulting metaphyseal fractures are analogous to Salter-Harris type II fractures. Third, this type of fracture pattern may be more likely to occur in males, like the cases presented herein, given the timing of physeal closure and the stability of the epiphysis, both of which are influenced by testosterone.[4,6]

As mentioned previously, the specific type of fracture described herein is not commonly encountered in clinical practice. This rarity may be attributable to the unique biomechanical stresses inherent to sport climbing. Furthermore, individual differences in age and

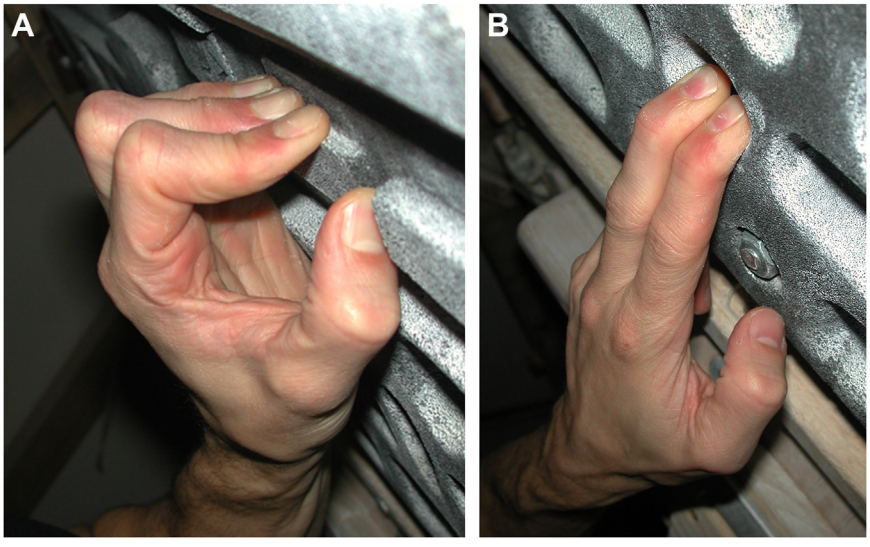

Figure 3. A, The "crimp grip" position with the proximal interphalangeal joints fully flexed and distal interphalangeal joints hyperextended. B, The "open grip" position is the most extreme grip position. In this arrangement, the distal interphalangeal joint is flexed and the proximal interphalangeal joint is almost completely extended. At times, a climber's entire body weight will be supported with the fingers in this position.

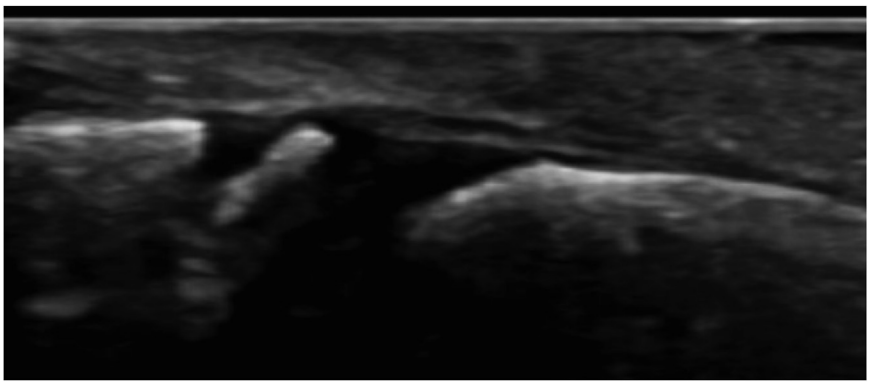

Figure 4. Ultrasound image of the dorsal aspect of the right middle finger's distal interphalangeal joint in a healthy 8-y-old child.

physiological variability may contribute to the development of this specific fracture type. Moreover, unless x-rays are obtained in a strict lateral view, this fracture type can be easily overlooked.

In both patients, a conservative treatment approach consisting of reduction in load-bearing activities of the finger and avoidance of terminal joint mobilization was successful. Therapeutic finger taping around the DIP joint prevents terminal joint flexion, specifically during return of activity.

Given that the "open grip" position explains the pathomechanics of this fracture type, we recommend a balanced training regimen in skeletally immature climbers (specifically those aged ≤18 y). The training should focus on increased volume and diversity of climbing routes rather than increased climbing intensity to help minimize the likelihood of injury and preserve the individuals' climbing capabilities over the long term.

Future investigations on this topic should explore whether there is an optimal amount and duration of activity restriction needed following stress fractures of the distal phalanx. Moreover, studies should seek to quantify whether (and to what degree) the resumption of normal activity prior to full bone consolidation increases the relative risk for secondary complications, long-term sequalae, or other unfavorable outcomes.

Given the rapid growth in the popularity of both professional and recreational sport climbers, recognition of this unique presentation and fracture pattern is clinically meaningful for healthcare providers who are engaged in the treatment of young patients who present with climbing injuries. In doing so, clinicians will be able to accurately diagnose and manage this rare but important fracture type.

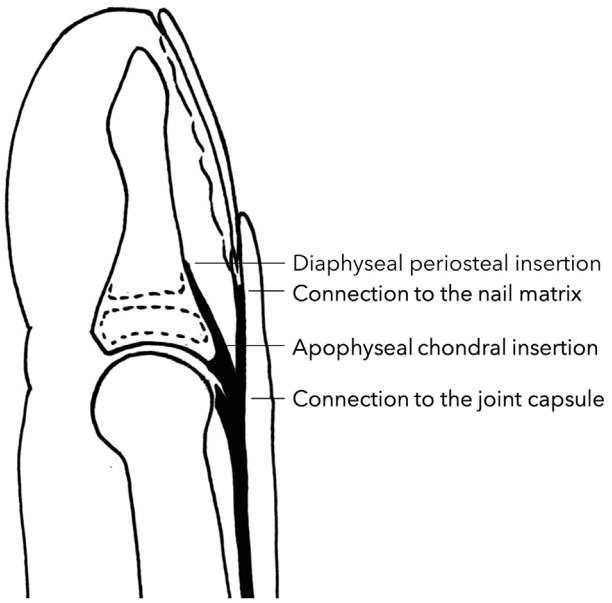

Figure 5. Graphic representation of the quadruple insertion of the pars terminalis of the dorsal aponeurosis (extensor tendon). After Frenz et al.[14]

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CONCEPTS

Time to Reconsider Analgesia in Mass Casualty Incidents

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The provision of analgesia in mass casualty incidents has traditionally been viewed as low-priority and reserved for later stages of care. Poor pain management is commonplace in trauma victims, and inadequate acute pain management can hinder evacuation efforts and may lead to the development of chronic pain and posttraumatic stress disorder. New, safe, and simple methods for administering quality analgesia have proven to be safe and effective in the prehospital setting and, as such, could easily be implemented into mass casualty incident protocols and allow for analgesia at earlier stages in such incidents, thereby improving patient care.

Keywords: fentanyl lozenge, methoxyflurane, Major Incident Medical Management and Support, prehospital emergency care, sublingual sufentanil, trauma

Introduction

The act of providing analgesia is often overlooked when planning and managing a mass casualty incident (MCI). In the most recent version of the *Major Incident Medical Management and Support* manual, analgesia is referred to only 7 times (out of 216 pages), and no details are given concerning the modalities of pain control in the mass casualty setting.[1] In the early stages of such events, the limited resources of emergency services and the great number of casualties mean that the scope of action of emergency personnel is usually limited to triage and providing essential life-saving interventions. Until now, analgesia has been deemed low-priority and reserved for later stages of management when resources become more abundant. New, easy, and safe ways of providing quality analgesia have shown promising results and may bridge the gap in allowing analgesia to be provided earlier in MCIs without needlessly consuming time or personnel, all the while increasing the quality of care to patients.

The *Major Incident Medical Management and Support* principles define a major incident as an "incident where the location, number, severity or type of live casualties requires extraordinary resources."[1] Recent events, such as the 2015 Paris attacks or the 2017 Manchester Arena bombing, have reminded us that planning and training for these situations are of paramount importance.[2] When attending and managing these types of events, the main goal has always been to do the most for the greatest number, which means identifying critical yet salvageable patients through triage and delivering life-saving interventions.[3] However, there has also been some criticism of the way we anticipate and prepare for these events. Current guidelines suggest implementing a robust command-and-control structure in major incidents, while some authors suggest that the way forward is by "supporting and facilitating" autonomous frontline teams.[4] Another suggestion for change in current practice has been that patients with minor injuries and expectant patients should also benefit from a portion of initially available care without having to wait until all critical cases have been managed and evacuated.[5]

There is, to our knowledge, no existing literature on the experience, satisfaction, and/or expectations of major incident survivors concerning analgesia on the incident site. However, there is lots of evidence to suggest that poor pain

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management is commonplace in trauma victims, even in resource-rich prehospital settings with a high provider-to-patient ratio.[6,7] Furthermore, certain population groups are particularly affected by oligoanalgesia in trauma (women, patients of color, elderly patients).[8] Poor management of acute pain may lead to the development of chronic pain and posttraumatic stress disorder.[9-11] By contrast, early and effective analgesia, apart from its humanitarian value, can help with reducing anxiety and assist with evacuation and splinting. Victims have testified about agonizing pain during evacuation and transport in mass casualty situations, and advances should be made to prevent these situations from happening.[12]

The military prehospital environment is a low-resource, high-acuity setting that could, to a certain extent and in certain situations, resemble a mass casualty setting.[13] To allow for effective analgesia in the field, the military has turned away from traditional ways to deliver analgesia, such as intravenous (IV) morphine, which requires cannulation and titration, and moved toward use of other means of analgesia, such as fentanyl lozenges.[14] More recently, some civilian Helicopter Emergency Medical Service providers have also added these to their inventory, with positive results and an excellent safety profile.[15]

The ideal analgesic administered in MCIs should have the following characteristics: easily administered, rapid onset, wide therapeutic index, minimal mental status alteration, and ideally not require the need for surveillance or monitoring. In this review, we do not discuss IV analgesia because cannula placement and titration of analgesics are excessively time-consuming in the early phases of an MCI. Furthermore, oral first-line analgesics, such as paracetamol and nonsteroidal anti-inflammatory drugs, will not be discussed either because, while their administration is simple and their safety profile excellent, onset of their effect is slow (usually >30 min) and their efficacy for traumatic moderate-to-severe pain is insufficient. The intramuscular (IM) route allows for easy and rapid administration of analgesics in patients without the need for an IV line. However, in patients with shock, the bioavailability of drugs administered through this route may be reduced. Morphine and ketamine are widely considered the gold standard in the treatment of moderate to severe pain in the prehospital setting. However, we will demonstrate they are not the best suited for analgesia in early MCI phases.

Morphine

Morphine has existed since 1805, when it was isolated from opium by Friedrich Serturner.[16] It remains one of the most widely used analgesics for moderate-to-severe pain and represents a standard against which most potent analgesics are compared in research.[17] It can be administered orally, subcutaneously, and via the IM and IV routes. Morphine has a slow central nervous system penetration, which results in delayed analgesic onset.[18] The risk of respiratory depression remains a concern with the use of opiates, and morphine's slow onset of action means that this complication may occur in a delayed fashion. For all these reasons, while morphine is extremely useful and effective when providing analgesia to one or a few patients at a time, including in the prehospital setting, it is an unsuitable candidate for mass casualty analgesia. Many other opioids have been developed or isolated, such as oxycodone, hydromorphone, hydrocodone, and codeine. They can be easily orally administered but suffer from similar limitations as morphine and, as such, are unsuitable for analgesia in MCIs.

Ketamine

Ketamine has long been, and remains, a drug of choice for prehospital analgesia in the setting of trauma and is widely and effectively used in austere settings.[19,20] While it is usually administered intravenously, it can be administered by IM or intranasal (IN) routes. The IN route is unpredictable, and the IM route is equally not ideal for reasons previously stated. The unpredictability of the IN and IM routes is acceptable when caring for one patient at a time, as the provider can adapt treatment following clinical response, but is unsuitable for MCI, where the surveillance of individual patients is limited. Ketamine is also appreciated for its lack of effect on respiratory drive, even though its dissociative effect at higher doses makes it a suboptimal choice in MCIs as it may impede evacuation efforts and influence triage scores.

Fentanyl

Fentanyl is a synthetic opioid 50 to 100 times more potent than morphine.[21] It has long been used in prehospital emergency medicine and is conveniently used IN in adults and children, including in austere settings.[22,23] Oral transmucosal fentanyl citrate (OTFC), in the form of lozenges, has seen extensive use in the military setting.[24] In a 2012 review of use on the battlefield, 286 patients received OTFC, and only 1 patient presented with hypoventilation and saturation of less than 90%, requiring low-dose naloxone, and this patient had received high-dose OTFS (3200 micrograms) in addition to 20 mg of IV morphine. Use in the civilian setting is beginning to become widespread, and a recent review of its use in 177 patients by emergency medical service providers in 3 bike and ski resorts in Switzerland showed good efficacy and no major

adverse effects.[25] Reported doses of OTFC in civilian prehospital use range from 400 to 800 micrograms.

Sufentanil

Recently, sufentanil has been made available in the form of sublingual tablets and is approved in Europe for postoperative pain. It has a high bioavailability with the lack of a first-pass effect, lack of active metabolites, and high lipid solubility. This allows rapid drug equilibration between peripheral and central compartments, resulting in rapid onset of analgesia. Its large therapeutic index, in addition to previously cited characteristics, makes it an interesting candidate for prehospital analgesia.[26] For the moment, no studies have evaluated its use in prehospital analgesia, but with further experience, sublingual sufentanil might become a useful drug for prehospital analgesia in the mass casualty setting. The optimal dose for use in this setting is to be determined.

Methoxyflurane

Methoxyflurane is a fluorinated hydrocarbon anesthetic. It is marketed as a single-use inhaler. Having been used in Australia for almost 50 y, methoxyflurane was only recently approved in Europe for use in traumatic pain in adults. Use in children is currently being investigated.[27] One inhaler allows for 25 to 30 min of analgesia with continuous use or almost up to an hour with intermittent use.[28] Analgesia is obtained rapidly (4–5 min); however, methoxyflurane was found to be less effective than IN fentanyl and IV morphine.[29]

Dose

The question of the dose must be determined in advance when planning for the use of single-dose transmucosal or sublingual analgesics in the mass casualty setting. A larger dose potentially means more complications, such as respiratory depression, and lower doses might result in suboptimal pain control. There cannot be a one-size-fits-all approach. One possibility would be color-coding devices and providing different doses, such as one dose for children, one for small adults/teenagers/elders, and another for large adults. To reduce complexity, a single, low-range dose could be provided, and 2 of those could be given to larger teenagers or adults.

Other Factors

Different factors may impact the implementation and use of transmucosal or inhalational analgesics for MCIs. The first factor is availability. Methoxyflurane is currently unavailable in North America, although efforts are being made to obtain US Food and Drug Administration approval.[30] The second factor is price, as these formulations are far more expensive than their IV counterparts. For example, a single fentanyl 200-microgram transmucosal lozenge costs 17 USD, while a 50-microgram vial costs 50 cents.[31] In the UK, a single methoxyflurane inhaler costs almost 18 GBP.[32] If these products are only acquired with the purpose of being used in rarely occurring MCIs, expiration dates and wastage are also important elements to consider. The last factor is size, as inhalers are much more cumbersome than transmucosal lozenges or sublingual tablets.

Conclusion

While life-saving interventions must be prioritized over analgesia, it is time we rethink the way we provide early, high-quality, safe analgesia to mass casualty victims. Providing analgesia in the early stages of an MCI cannot be simply thought of as upscaling usual prehospital analgesia. As such, traditional ways of providing analgesia with IV morphine and ketamine might be inadequate in these situations. Other ways of delivering analgesics, such as transmucosal fentanyl lozenges or inhaled methoxyflurane, might bridge the gap by allowing patients to benefit from early pain control. More recently, the release of sublingual sufentanil is an exciting development in available options for analgesia in the prehospital setting. Mass casualty events are highly traumatizing to victims, and any way we can find to alleviate the suffering of injured victims as early as possible must be a priority and planned for accordingly.

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REVIEW ARTICLE

Use of Unmanned Aerial Vehicles in Wilderness Search and Rescue Operations: A Scoping Review

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Wilderness Search and Rescue (WSAR) focuses on locating and extricating missing persons in remote settings. As unmanned aerial vehicle (UAV) or "drone" technology has evolved, so has the literature describing its application in WSAR operations. We conducted a scoping review of literature that describes the use of UAVs in WSAR contexts. The Joanna Briggs Institute Framework for scoping reviews was followed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews method. Additional individual databases, article reference lists, and relevant grey literature were also included in the search to provide an impartial scope. Seven hundred forty-seven articles were identified. Of these, 56 were found to be duplicates. The remaining 691 were further screened and checked for eligibility. Ultimately, 21 studies were found that met our inclusion criteria. This literature supports the use of UAVs to increase the safety and efficiency of a WSAR operation for locating victims, assessing risks, carrying equipment, and restoring communication systems. Unmanned aerial vehicles are a potentially useful adjunct in the management of WSAR operations. Their limitations include objects obscuring victims, weather changes, uneven terrain, battery-limited flight time, and susceptibility to environmental damage.

Keyword: drone

Introduction

Wilderness Search and Rescue (WSAR) teams are often deployed to search for, locate, and extricate individuals who are overdue, missing, lost, and/or possibly injured in remote areas and wilderness settings.[1] Wilderness Search and Rescue operations are generally considered to be time-critical, for delays in locating the victim may decrease their probability of survival.[1] Consequently, the search and locate phase of a wilderness rescue operation commonly requires the urgent sourcing and allocation of manpower and related resources, some of which may not be immediately available.[1,2]

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Over the past few years, unmanned aerial vehicles (UAVs) or "drones" have shown the potential to shorten search and locate times, accelerate rates of intervention, minimize risks for rescuers and victims, and present a cost-effective alternative to conventional WSAR search techniques.[2-4] Proponents of the application of UAV technologies in WSAR contexts cite a number of potential advantages for the rescue team.[2,3,5] This said, there are also a number of limitations to their use. Consequently, decisions to purchase and operate UAVs in resource-constrained rescue settings should be defended against scientific evidence of their value and role in such contexts. We conducted a scoping review of the literature that describes the use of UAVs in WSAR contexts. This scoping review provides an assessment of the available evidence relating to the potential role and value of using UAVs in WSAR operations, including some of their limitations.

Methods

We followed the methodology and steps of the Joanna Briggs Institute Framework for the conducting of scoping

reviews.[6] The Preferred Reporting Items for Systematic Reviews and Meta-Analyses Extension for Scoping Reviews (PRISMA-ScR) flow diagram was used to guide the data collection processes.[7] The approaches and steps followed in the context of our study are summarized below.

STEP 1: DEFINING THE TITLE

The title we derived to guide our review became "Use of Unmanned Aerial Vehicles for Wilderness Search and Rescue Operations: A Scoping Review."

STEP 2: DEVELOPING THE REVIEW QUESTION

The research question we developed for this study became "What literature is available that describes the use of UAVs in WSAR operations?"

STEP 3: DECIDING ON THE FORMAT AND APPROACH

Our results are described according to the PRISMA-ScR flow diagram.[7]

STEP 4: DEFINING THE INCLUSION AND EXCLUSION CRITERIA

Our inclusion criteria became any literature focusing on UAVs in WSAR operations. We excluded literature on UAVs outside of WSAR contexts and literature that was not available in English.

STEP 5: DEFINING THE SEARCH STRATEGY

The following databases were used: Cumulated Index to Nursing and Allied Health Literature (CINAHL), Cochrane, Medline, and Scopus. The reference lists of the identified articles were further screened for additional literature, and any relevant grey literature that was found was also included. Initially, the following combination of terms and keywords was used: "drones," "unmanned aircraft vehicles," "unmanned aerial vehicle," "remotely piloted vehicle," "unmanned aviation vehicles," and "wilderness search and rescue." During the searches, additional terms and keywords were discovered. Where relevant, these were also considered to broaden the initial search. The search was conducted between July 2022 and August 2022.

STEP 6: DATA SELECTION AND MANAGEMENT

The PRISMA-ScR selection process flow diagram for scoping reviews was used to guide and illustrate the data selection process of this review.[7] After identifying data from the databases, the literature and relevant grey literature were imported to an Excel spreadsheet, where all duplicates were removed. The titles of the literature were then screened; those titles that fit the brief together with nonspecific titles were retained for abstract screening. After title and abstract screening, the full-text versions of the remaining manuscripts were critically reviewed for inclusion considering the aim and objectives of the study.

STEP 7: DATA EXTRACTION

Data extraction was completed using extraction forms and tables. The Joanna Briggs Institute data extraction form [6] was used to guide the researcher in identifying data sources, characteristics, and results. Each of these was tabulated under the headings included in Table 1.

STEP 8: ANALYSIS OF THE EVIDENCE

The data were extracted, synthesized, mapped, and interpreted to determine frequency of characteristics, concepts, and occurrences.

STEP 9: PRESENTATION OF THE RESULTS

Our results are presented in the form of tables, charts, and narrative summaries in the sections that follow.

Results

The results of the scoping review are summarized in Table 1. Of the 276 articles identified through database searches of Scopus (187), PubMed (82), CINAHL (5), and Cochrane (2), 21 records were found that met the inclusion criteria.[2,3,5,8-25] The data extracted from these 21 records are summarized in Table 1. The final 3 columns of Table 1 summarize the different authors' pronouncements on the type, usefulness, terrain, and context of the UAVs featured in their study.

DATE OF PUBLICATIONS AND COUNTRY OF ORIGIN

Thirteen records were published within the past 5 y,[5,14-25] 7 records in the last 6 to 10 y,[2,3,9-13] and 1 record was found that was older than 10 y.[8] No records were excluded based on their age. The majority of records included in the review came from the United States of America, contributing 7 records,[2,5,8,13,16,19,20] and Austria with 3 records.[17,21,22] Turkey,[3,25] Italy,[12,22] and Poland [11,15] contributed 2 records each. One record had overlapping origins, namely, Austria and Italy.[22] There was 1 record contribution each from Norway,[9]

Table 1. Summary of the data extracted from the included records

Author, year	*Origin*	*Aim*	*Population and sample size*	*Research design*	*Flight time (min)*	*Terrain and context*	*Outcomes*	*Type of UAVs featured in the study*	*Reported usefulness of UAV technology*
Goodrich,[8] 2009	USA	Assess the usage of a UAV in WSAR	Not specified	Usability study	90	Forest; autonomous fixed wing; path planning and search patterns	Case 1: unsuccessful Case 2: victim located	Not specified	UAVs can be used to support WSAR operations
Abrahamsen,[9] 2015	NO	Assess feasibility of using a UAV system to support remote sensing	27 simulated victims	Feasibility study	<15	Mountain; piloted multirotor with thermal imagery	All simulations successful	Not specified	UAVs can deliver tools and support situational assessment
Cacace et al,[10] 2016	CH	Assess a control architecture for multiple UAVs in WSAR	Not specified	Feasibility study		Mountain; autonomous multirotor; search patterns; software control	The control architecture is effective	Not specified	UAV technologies can effectively be utilized in WSAR
Levin et al,[11] 2016	PO	Assess feasibility of UAVs with thermal imaging	1 simulated victim	Feasibility study	18 14	Forest; multirotor with thermal imagery	Thermal imaging allows live-victim detection	DJI Inspire I; 3DRn IRIS	Thermal imaging UAVs are effective in WSAR operation
Silvagni et al,[12] 2017	IT	Assess usage of UAVs with thermal cameras and an avalanche beacon	Not specified	Usability study	30	Mountain; autonomous multirotor; thermal imagery; path planning	The UAV system if effective	PRO S3 Venture	UAVs can support WSAR operations
Van Tilburg,[2] 2017	USA	Report on a UAV used in WSAR	2 victims	Case report	25	Mountain and canyon; piloted multirotor	Case 1: victim located Case 2: unsuccessful	Aerial Technology International SAR Bot	UAVs can be used to confirm fatalities and aid WSAR operations

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Table 1 *(continued)*

Author, year	*Origin*	*Aim*	*Population and sample size*	*Research design*	*Flight time (min)*	*Terrain and context*	*Outcomes*	*Type of UAVs featured in the study*	*Reported usefulness of UAV technology*
Kesteloo,[13] 2018	USA	Report on a UAV used in WSAR	1 victim[a]	News report	27	Mountain; piloted multirotor	Victim located	DJI Mavic Pro Multirotor	UAVs can be used to locate victims
Karaca et al,[3] 2018	TR	Compare classic search techniques with UAV search techniques	Not specified	Randomized simulation		Mountain; piloted multirotor	Located all mannequins	DJI Phantom 3 Pro	Victims can be located faster with a UAV
McRae et al,[5] 2019	USA	Report on a UAV used in WSAR	1 victim[a]	Case report	27	Mountain; piloted multirotor	Victim located	DJI Mavic Pro Multirotor	UAVs can be used to locate victims
McKenzie,[14] 2018	UK	Report on a UAV used in WSAR	1 victim[a]	News report		Mountain; piloted multirotor	Victim located	Not specified	UAVs can be used to locate victims
Podsiadło et al,[15] 2019	PO	Report on a UAV used in WSAR	2 victims[a]	Case report	27	Mountain; piloted multirotor	Victim located; medication delivered successfully	DJI Mavic Pro Multirotor	UAVs can locate and guide victims and deliver medicine
Hanrahan,[16] 2020	USA	Report on a UAV used in WSAR	1 victim	News report	30	Forest	Victim located	Not Specified	Police used UAV to locate the victim
Schedl et al,[17] 2020	AT	Assess if detection rate in WSAR can improve by combining UAV images	57 simulated victims	Feasibility study	20	Forest; autonomous multirotor; AOS	53 of 57 persons located	MikroKopter OktoX 6S12	Detection rate is improved by using UAV obtained images
Rodriguez,[18] 2020	GR	Assess if a multirobot system can improve UAV usage in WSAR	Not specified	Feasibility study		Mountain	Completed 10 of 10 tasks	Not Specified	The system is effective in controlling multiple UAVs
Weldon and Hupy,[19] 2020	USA	Assess viability of object identifying software in WSAR with a UAV	Not specified	Simulation study	38 150	Forest; autonomous fixed wing; color identification software	Software identified all objects	C-Astral Bramor PPX	UAV software can assist in identifying victims

(continued on next page)

Table 1 *(continued)*

Author, year	*Origin*	*Aim*	*Population and sample size*	*Research design*	*Flight time (min)*	*Terrain and context*	*Outcomes*	*Type of UAVs featured in the study*	*Reported usefulness of UAV technology*
McRae et al,[20] 2021	USA	Assess if communication in WSAR can be improved with a UAV	Not specified	Feasibility study	10	Mountain and canyon; piloted multirotor; repeater system	Communication restored in all tests	DJI Mavic 2 Pro	Failed communication can be restored with a UAV
Schedl et al,[21] 2021	AT	Assess an autonomous UAV with airborne optical sectioning in WSAR	42 simulated victims	Feasibility study	20	Forest; autonomous multirotor; thermal camera; AOS	38 of 42 hidden persons found	MikroKopter OktoX 6S12	UAVs with airborne optical sectioning can support WSAR operations
Wankmüller,[22] 2021	AT, IT	Explore usability of UAVs in cross-border WSAR	288 simulated victims	Usability study	20–48	Mountains; piloted multirotor		Air6 Systems Air8; Autel Robotics EVO II; DJI Mavic 2 Zoom; DJI Mavic Enterprise Zoom; DJI Mavic Mini; MAVTech Q4T; DJI Mavic Air; Soleon Coanda X6	UAVs have multiple uses in WSAR operations
Nomalanga,[23] 2021	SA	Report on a UAV used in WSAR	2 victims	News report		Aquatic (coast) and mountain	1 of 2 victims located	Not specified	UAVs can be used to locate victims
Yeom,[24] 2021	KR	Assess a detection and tracking system with a thermal imaging UAV	13 simulated victims	Feasibility study	27	Mountain; infrared thermal camera and detection software	13 of 13 objects located	DJI Inspire 2	The detection and tracking system is useful in WSAR

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Table 1 (*continued*)

Author, year	*Origin*	*Aim*	*Population and sample size*	*Research design*	*Flight time (min)*	*Terrain and context*	*Outcomes*	*Type of UAVs featured in the study*	*Reported usefulness of UAV technology*
Cicek et al,[25] 2022	TR	Compare drone-assisted SAR with classic SAR techniques	Not specified	Simulation	31	Aquatic (river); piloted multirotor	Located all dummies	DJI Mavic 2 Pro	UAV searches are faster than ground-based searches

UAV, unmanned aerial vehicle; USA, United States of America; WSAR, Wilderness Search and Rescue; NO, Norway; CH, Switzerland; PO, Poland; IT, Italy; SAR, search and rescue; TR, Turkey; UK, United Kingdom; AT, Austria; AOS, airborne optical sectioning; GR, Greece; SA, South Africa; KR, Korea.
[a]Same victim.

England,[14] Switzerland,[10] Greece,[18] Korea,[24] and South Africa.[23]

CORE FOCUS AND AIMS

The records identified revealed similar characteristics with regard to their focus and aim. Seven records focused on searching for a real victim with the support of a UAV.[2,5,13-16,23] There were 4 records that focused on the general feasibility of utilizing a UAV in WSAR operations.[8,9,20,22] Two records compared the usage of UAVs with classic ground SAR techniques.[3,25] The development and testing of a system or software that could be used to improve the usability of a UAV in WSAR was the focus of 8 records.[10-12,17-19,21,24]

METHODOLOGY

The studies referred to in the records could be divided into retrospective (n=7) and prospective designs (n=14). The designs were further divided by method and approach; these included case reports (n=7) and experimental studies (n=14). The experimental studies further comprised feasibility studies (n=8), usability studies (n=3), and randomized simulation studies (n=3). The mean sample size for all the records was 29 simulated operations and patients and 1 patient in authentic contexts. Six records focused on simulated operations, and 7 studies reported on real-life operations. Eight records did not specify a sample size, nor did they include human participants.

ENVIRONMENT AND CONTEXT

All the records identified reported on operations that were conducted in wilderness settings (as per inclusion and exclusion criteria). However, as the term "wilderness environment" was not clearly defined in the literature in terms of terrain, it became difficult to accurately link the different studies to a specific wilderness environment based on the information that was provided in the records.

TYPES OF UAVS USED

Various models of UAVs were described throughout the records, each having different specifications. The majority of the UAVs featured in the records could be considered "entry" to "mid-level" battery-powered units. This is in contrast to larger "high-end" commercial and military type UAVs, which have bigger payloads, extended flight times, and are considerably more expensive. The UAVs conventionally used in WSAR contexts have payloads and operation times that are seen as "limited" in comparison to high-end units, with the

majority of authors highlighting their flight times as a significant limitation. A summary of these is presented in Table 1.

Discussion

Wilderness Search and Rescue teams are commonly required to locate and rescue individuals who are lost, ill, or injured in remote wilderness environments.[1,8] Wilderness settings differ considerably by climate, vegetation, and terrain. The type of terrain and environment has a great impact on the WSAR operations. Often, it is the harsh environment itself that creates the need for rescue in the first place.[8] The use of UAVs may play a role in limiting the unnecessary exposure of rescuers to environmental risks and potentially shorten the time taken to conduct a WSAR operation.

ROLE OF UAVS IN RISK MITIGATION

Identifying and limiting risk is important in all rescue operations. Karaca et al,[3] Weldon and Hupy,[19] and Abrahamsen[9] found that utilizing UAVs in WSAR operations can improve risk identification and mitigation. Unmanned aerial vehicles can be deployed to survey and search areas that are not immediately accessible or too dangerous to rapidly clear by ground personnel. Scouting and analyzing areas in advance will also provide rescuers with better situational awareness, allowing risk mitigation strategies to be implemented for rescuers who are required to physically access and search the area.[4,9,19]

Having a good communication system is crucial in any WSAR mission.[20,22] An inability to communicate with team members effectively poses several risks. The feasibility of using a UAV to restore radio communication during SAR operations was investigated by McRae et al.[20] The study conducted multiple field tests where a UAV equipped with a radio repeater was used to restore radio communication between SAR personnel.[20]

One record describes a rescue in the Himalayas where a UAV was successfully used to locate a missing climber, ultimately leading to his rescue.[5,13-15] The authors indicated that use of the UAV removed the need for human searchers to search a large area that was potentially unstable, unnecessarily.[5,13-15] Similarly, Nomalanga[23] agreed that UAVs serve a valuable function in risk mitigation strategies by reporting on the use of the South African Western Cape Government Department of Health's UAV in different wilderness rescue incidents, including a search for a victim who had jumped off a cliff into the ocean. Although the victim was never located, the use of the UAV meant that the risks associated with launching and use of boats and rescue swimmers in a dangerous area were avoided.[23] Van Tilburg[2] described how in Oregon a UAV was used to confirm a fatality in a canyon (using images acquired by the pilot), thus eliminating the need for rescuers to urgently climb down into the canyon. Rather, they were able to plan and access the area the following day.

REDUCING THE TIME TAKEN TO LOCATE THE VICTIM

Wilderness Search and Rescue operations are seen to be time-critical as the victims' survival probability decreases with time.[3,12] We found the literature to be replete with examples of how UAVs have allegedly sped up the process of locating the victim. Hanrahan[16] reported on how the police department of Enfield, Connecticut, searched for a blind man who had been missing for more than 30 h in winter. The use of a UAV allowed the rescue teams to locate the man within half an hour.

Karaca et al[3] and Cicek et al[25] compared the differences between human searchers and UAVs in WSAR. Their studies used field experiments to compare search times between classic human search techniques and UAV searches separately. Although these studies used simulated rescue incidents, the results support the findings of Nomalanga[23] and Hanrahan[16] that UAVs allow victims to be located faster.

IMPACT OF ADVANCES IN UAV TECHNOLOGY

Unmanned aerial vehicles are becoming ever more upgraded and equipped with additional accessories that can widen their scope and improve their usability and detection rates in WSAR operations.[3] Rodriguez[18] and Cacace et al[10] explored the use of different multirobot systems to control and navigate multiple UAVs simultaneously. The feasibility of the software was tested to autonomously allocate UAVs to individual tasks, eliminating the need for multiple UAV pilots and rescuers to search areas.[9,18]

Six studies mentioned utilizing UAVs equipped with thermal imaging.[9,11,17,21,22,24] Of these, the core aim of 2 of the studies was to explore the feasibility of thermal imaging to detect victims and to confirm if they were still alive.[11,24] In WSAR contexts, thermal imaging was found to be a useful aid in detecting live victims.[17] Although these technologies may be helpful, manual scanning of aerial images (in hopes of detecting a victim) was found to be challenging and time-consuming. Manual scanning has been shown to come with a risk of "false detection" due to human error and developing mental fatigue.[19] The development and use of identification software to assist with detecting victims was found to be helpful.[19]

Identification software makes use of algorithms to detect victims. Five records were found that focused on human detection algorithms, and the authors all seem to come to a similar conclusion that utilizing software to aid rescuers in detecting victims through technology saves time and reduces the manpower required to assess aerial images.[11,17,19,21,24]

The studies also showed that the automation software and approaches themselves differ considerably. Weldon and Hupy[19] describe software that uses color-based spectral signatures to identify objects. Levin et al[11] explored the use of electro-optical sensors with thermal imaging to detect humans. Airborne optical sectioning software was used by Schedl in 2 studies, in which the program combines multiple aerial images and removes occlusions or obstructions to improve human detection.[17,21] Yeom[24] described a dual object detection method whereby K-means clustering software and infrared thermal imaging were used. K-means clustering is a method for image segmentation by subtracting the interest area from the background.[24] This makes detection of hot spots on thermal images easier as it includes assessment of the object size, color, and heat signature.

PILOTING AND PATH PLANNING

Search planning is important, as poorly planned searches can waste time and may result in victims either being left undetected or creating a need to revisit an already searched area.[19] The literature described UAVs with autonomic and manual piloted modes. Eleven studies were found that reported on the use of manually piloted UAVs,[2,3,5,25,9,13-15,20,22,23] with 8 studies describing autonomous control systems that also had the capability of switching over to manual pilot mode if required.[8,10,12,17-19,21,24]

Autonomous modes may free up hands as the UAV can be preprogrammed to navigate and fly a specific route or pathway autonomously while continuously capturing aerial images of the area it has covered.[8,21] Five studies featured this type of path planning as an aid to rationalize and simplify the use of UAVs by WSAR teams.[8,12,17,19,21] The literature describes different flight patterns for searching an area, with the "lawnmower" style grid being the most popular as it allows good coverage of an area in the shortest time possible. The lawnmower search pattern is one in which the UAV gathers imagery by following a preprogrammed flight path in a manner ensuring that the flight paths slightly overlap.[19]

Adaptive path planning differs from classical path planning. Adaptive path planning comprises an autonomous UAV with a real-time on-board classification system that can autonomously detect potential victims during the aerial search. When the classifier detects a potential victim, the UAV will automatically and adaptively plan to re-search that area, thus improving detection rate.[21]

LIMITATIONS TO THE USE OF UAVS IN WSAR

Locating victims with a UAV conventionally requires the victim to be visible from the sky. Various wilderness environments exist that limit human detection from the air. These include environments that have steep or uneven terrain, vegetation, mist, and snow, which may significantly obscure the view of a victim.[2,3,21] Unmanned aerial vehicles equipped with thermal imaging also have limitations, for they rely on detecting temperature differences between the environment and that of the victim. Challenges can be experienced when the victim's heat signature becomes hidden or blurred by heat signatures emanating from the surrounding environment.[17,21] Weather can also drastically change during a wilderness rescue operation. This can result in delays or an absolute inability to deploy a UAV.[2,8] Images taken by the UAV in such cases may also not be optimal, especially if one has to operate at high altitudes and within foggy conditions.[3]

Limited flight time is another widely acknowledged limitation to the use of UAVs in many different contexts. The literature reviewed describes different types of UAVs, each with a different flight endurance. The shortest reported flight time featured in the literature was 10 min, and the longest flight was cited as being 150 min.[8,20] Flight time not only affects the time available to search but consequently also limits the size of the area that can be searched, including the number of flights required to complete a search of a predetermined area.[8] Other well-recognized limitations to the use of UAVs, not specifically highlighted in the sources, include the cost of the technologies, the availability of experienced pilots, and legislative restrictions to their deployment in certain locations that may have protected airspaces.

Conclusions

Through the scoping review, 21 sources of literature were found that focused on use of UAVs in WSAR operations. Unmanned aerial vehicles can serve as a valuable tool for WSAR teams to complete environmental risk assessments, locate victims via aerial surveillance, and restore communication systems. Their limitations are noted to include objects obscuring victims, uneven terrain, cost, battery-limited flight time, and their susceptibility to weather changes and environment related damage.

Limitations and Suggestions for Future Research

We found that the terminology used across the records with regard to UAVs was at times vague, and multiple terms exist for "drones." Utilizing a single term for a UAV with regard to WSAR operations would be better to avoid misunderstandings as to which aerial vehicle is being used and to ensure that future searches of this nature are made easier. Another significant limitation in our view is the fact that there is not a great deal of literature around the area of WSAR specifically. Consequently, the WSAR terminology may not be universally understood. The fact that only articles written in English were included is acknowledged as a potential limitation. In addition, we noted the scientific "rigor" was possibly lacking in a certain number of the studies, either with the methodology being incompletely described or insufficient when it came to sample sizes and measuring the true value of UAVs in WSAR operations. Limited studies were found that focused on authentic WSAR operations, with many being mainly descriptive in nature. We suggest that additional research should be considered that focuses on reporting and describing the use of UAVs in actual SAR missions and how the value of incorporation of UAVs can be more scientifically quantified. There is also a need to further explore which types of SAR and/or disaster incidents would best benefit from the deployment of a UAV.

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ORIGINAL RESEARCH

A Finger in the Game: Sport-Specific Finger Strength Training and Onset of Injury

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Introduction—Strength training has proved to be an effective way to prevent injuries, but the evidence of the impact of strength training on finger injuries is lacking. A fingerboard is a sport-specific tool used by climbers for strength training of fingers. In this study, we searched for associations between fingerboard training and finger injuries in climbers with different lengths of climbing experience and levels of performance.

Methods—A web-based survey was used to collect information on self-perceived pain or injury in fingers (SPIIF) and regular fingerboard training (RFT). The survey was administered to the Finnish climbing community. Data were analyzed using contingency tables; chi-square was used to evaluate statistical significance.

Results—No significant correlations between SPIIF and RFT were found when analyzing all the participants (n=434) together. In climbers with 6 y or more in the sport, SPIIF was not common and RFT was negatively associated with SPIIF (χ^2 [1, n=200]=4.57; P=0.03). In contrast to this, in male climbers who had been climbing for less than 6 y and had advanced to 7a level or higher (French lead/Font bouldering), SPIIF was common and RFT was positively associated with SPIIF (χ^2 [1, n=75]=4.61; P=0.03).

Conclusions—We suggest that doing RFT may prevent SPIIF in climbers with a long background in the sport as fingerboard training can help build stronger fingers and thereby stronger tendons and ligaments. Climbers with fewer years in the sport and less adaptation to the fingers should be cautious with their training loads and RFT to avoid finger injuries and pain.

Keywords: rock climbing, fingerboard training, hangboard training, finger injuries, climbing injury prevention

Introduction

Climbing is a new Olympic sport with a growing number of participants and venues for the sport. With growing popularity, sport-specific injuries are increasing.[1] However, modern sport climbing is considered to have a low risk of severe injuries.[2]

The most common site of climbing-specific injuries is the fingers, and a significant proportion of finger injuries are overuse injuries.[2-4] More than 40% of chronic climbing injuries are finger injuries, and 67% of climbers have experienced a finger injury during the past 36 mo.[3,5] To our knowledge, there are no prior studies about the mechanisms of overuse injuries in climbing. In general, overuse injuries are often caused gradually by repetitive microtraumas.[6] Progressive training and controlled training loads appear to be key methods to prevent finger injuries.

The anatomical sites in fingers prone to injuries—annular pulleys, finger flexor tendons, finger collateral ligaments, volar plates, and finger bones—adapt to the load caused by climbing.[7-11] Some of these adaptations are already seen in young climbers, but adaptations often take multiple years of high-level climbing to develop.[7-12] For some of these adaptations

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(tendons and bones), the high load seems to be more effective than volume or frequency.[11,13]

A fingerboard (Fig. 1 and 2) is a climbing-specific training tool used by many climbers to strengthen fingers.[14] A fingerboard contains grips of various sizes to hang from or to conduct pull-up–related exercises.[15] Hanging is usually performed with body weight or added weight.[15] Load reduction with a pulley system is also possible. The possibility to control load, change the grip size or type, and vary the amount and length of repetitions and recovery time allows controlled and systematic finger training. Fingerboard training has been shown to increase finger flexor strength in climbers more than climbing alone.[16,17]

Neuromuscular training, and especially strength training targeting athletes' intrinsic risk factors, is an effective way to reduce acute and overuse injuries.[18-21] Currently, most studies of neuromuscular training and injury prevention are focused on team sports and injuries in the lower extremities or shoulders. However, the mechanism of strength training as a method to increase tissue capacity and thus prevent sports injuries is suggested to be generally applicable to other sports as well.[19,22] To our knowledge, there are no studies on strength training as a tool to prevent finger injuries in climbing. This study aims to evaluate the influence of fingerboard training on finger injuries in climbers with different lengths of climbing experience and levels of performance. We hypothesized that regular fingerboard training (RFT) is negatively associated with finger injuries.

Methods

The research setting was nonpersonal and anonymous. According to the Finnish National Board on Research Integrity TENK, this type of research setting does not require ethical review from the committee. However, good ethical research principles in data collection, analysis, and publication were closely followed.

Figure 1. An example of a fingerboard.

Figure 2. An example of a fingerboard.

DESIGN, PARTICIPANTS, AND SETTING

This study is based on an anonymous, cross-sectional, retrospective survey using a web-based questionnaire. The questionnaire was shared on national and locally based Facebook pages used by the Finnish climbing community. Furthermore, the link to the survey was reposted by others to an unknown extent.

The survey was open for respondents between May 9 and July 31, 2019. Only respondents who answered all of the questions; were aged 18 y or older; practiced climbing on a regular basis, once a week or more; and were doing at least one of the following climbing disciplines: bouldering, sport climbing, indoor bouldering or indoor lead climbing, were included in the study.

PARTICIPANT CHARACTERISTICS

The survey included questions on climbers' age, sex, height, and weight. The maximal achieved level of performance during the past 12 mo was asked, either according to the French lead climbing or the Font bouldering scale (≤6a+, 6b–6c+, 7a–7b+, 7c–8a+, and ≥8b). The respondents were asked how many years they had been doing regular climbing; how often they were climbing; whether they preferred bouldering, route climbing, or both; and whether they were climbing mainly indoors, outdoors, or both. The data were analyzed in 3 parts: females only, males only, and combined. Groups of climbers with a longer career (≥6 y of climbing), climbers with a shorter career (<6 y of

climbing), climbers with a higher level of performance (≥7a as in Lion et al[5]), and climbers with a lower level of performance (<7a) were analyzed separately, as well as climbers who only did bouldering.

FINGERBOARD TRAINING

Fingerboard training regimens were identified by asking whether respondents trained regularly on fingerboards. Several more questions were asked to clarify the frequency and nature of fingerboard training. Fingerboard training that happened regularly, at least monthly, was defined as RFT.

SELF-PERCEIVED PAIN OR INJURY IN FINGERS

Self-perceived pain or injury in fingers (SPIIF) was assessed by asking the respondents if they had any pain or injury in their fingers or palm, forcing them to have a total break from climbing, climb cautiously, or restrict climbing during the past 6 mo. An additional question about the location of SPIIF helped to rule out a few cases of injuries that did not affect the finger or palm area.

STATISTICAL ANALYSES

The data were analyzed using SPSS Statistics (version 27 for Mac; SPSS INC, Chicago, IL). Possible associations between relevant variables were assessed with contingency tables. Chi-square was used to evaluate the statistical significance of the relationships. The statistical significance level was set at $P<0.05$.

Table 1. Participant characteristics

	All (n=434)	*Females (n=158)*	*Males (n=276)*
Age (y), mean	33.6	33.0	33.8
BMI (kg/m^2), mean	22.9	21.8	23.4
Level of climbing, n (%)			
4–6a+	33 (8)	25 (16)	8 (3)
6b–6c+	135 (31)	65 (41)	70 (25)
7a–7b+	186 (43)	62 (39)	124 (45)
7c–	80 (18)	6 (4)	74 (27)
Years climbing, n (%)			
<1 y	30 (7)	12 (8)	18 (7)
1–2 y	71 (16)	34 (22)	37 (13)
3–5 y	133 (31)	52 (33)	81 (29)
6–10 y	123 (28)	40 (25)	83 (30)
>11 y	77 (18)	20 (13)	57 (21)
Frequency of climbing, n (%)			
1–2 times a wk	165 (38)	76 (48)	89 (32)
3–4 times a wk	252 (58)	79 (50)	173 (63)
5 times a wk or more	17 (4)	3 (2)	14 (5)
Venue of climbing, n (%)			
Indoors	150 (35)	55 (35)	95 (34)
Outdoors	13 (3)	3 (2)	10 (4)
Indoors and outdoors	271 (62)	100 (63)	171 (62)
Style of climbing, n (%)			
Bouldering	169 (39)	47 (30)	121 (44)
Route climbing	45 (10)	28 (18)	17 (6)
Bouldering and route climbing	220 (51)	83 (53)	137 (50)

BMI, body mass index.

Results

PARTICIPANT CHARACTERISTICS

The participants' (n=434) ages ranged from 18 to 59 y; the mean age was 34 y. Of the participants, 158 (36%) were women and 276 (64%) were men. A majority of the respondents had been climbing for over 3 y and were climbing 3 to 4 times a week. For most participants, the level of performance was 7a to 7b+. As only 1 respondent was climbing at a harder level than 8b, the 2 highest groups were merged in the final analysis. Most respondents were climbing both indoors and outdoors and performing bouldering as well as route climbing (Table 1).

FINGERBOARD TRAINING

Of all the participants, 24% were doing RFT. Regular fingerboard training was more common among men (31%) than among women (11%). Regular fingerboard training was common among the climbers with a higher level of climbing performance: 15% of level 4 to 6a+ climbers, 12% of 6b to 6c+ climbers, 25% of 7a to 7b+ climbers, and 45% of 7c– climbers did RFT.

Fingerboard training was mainly performed 1 to 2 times a week. Almost all respondents described their fingerboard training as either maximal finger flexor training or intermittent hangs ("repeaters"). Maximal finger flexor training was typically performed by hanging for 5 to 10 s with maximal weight, and intermittent hangs typically performed by hanging for 5 to 10 s and resting for 3 to 5 s multiple times in a row. The respondents were mainly hanging their body weight with 2 arms or hanging with 1 arm or using added weight (see Table 2).

SPIIF

Of the respondents, 42% reported that SPIIF affected their training during the past 6 mo (see Table 3). Self-perceived pain or injury in fingers was equally present in women (41%) and men (42%). No significant

Table 2. Fingerboard training (intensity, load, number of weekly sessions)

	Mean (±SD) or n (%)
Intensity of fingerboard training	
Female	5.2 (±1.5)
Male	6.1 (±1.2)
Fingerboard training load	
Reduced body weight	1 (1)
Body weight and hanging with 2 arms	38 (37)
Added weight or hanging with 1 arm	39 (38)
Alternating between added and reduced weight	25 (24)
No. of fingerboard sessions	
Less than 1 per wk but more than 1 per mo	5 (5)
1–2 per wk	93 (89)
>3 per wk	6 (6)

correlations were found between SPIIF and the frequency of climbing.

FINGERBOARD TRAINING VS SPIIF

When analyzing all the participants together, there were no significant correlations between SPIIF and RFT as SPIIF was almost as common in the groups of climbers doing RFT as it was in the groups of those not doing RFT (39% vs 43%). In women who did RFT, SPIIF was not as common as in the group of women who did not do RFT (28% vs 43%), but the difference was not significant (χ^2 [1, n=158]=1.50; P=0.22).

For those who had been climbing for 6 y or more, fingerboard training was negatively correlated with SPIIF (χ^2 [1, n=200]=4.57; P=0.03). In this group, 28% of those who did RFT had experienced SPIIF during the past 6 mo. Of those who did not train on fingerboard, 44% had faced SPIIF during the past 6 mo (see Table 4).

Among male climbers who had been climbing for less than 6 y and whose level of performance was 7a or higher, 78% of those doing RFT had experienced SPIIF. Of those who did not do RFT, 52% had experienced SPIIF (see Table 4). The relationship between these variables was significant (χ^2 [1, n=75]=4.61; P=0.03). The tendency was even more clear in climbers who were only bouldering. Of male boulderers who had been climbing for less than 6 y, whose performance level was 7a or higher, and who did RFT, 85% had encountered a finger injury during the past 6 mo (χ^2 [1, n=46]=4.29; P=0.04).

Discussion

This study suggests possible connections between RFT and SPIIF. We found that in climbers who had been climbing for 6 y or more, RFT was associated with a lower risk of SPIIF. Furthermore, for male climbers who had been climbing for less than 6 y and whose level of performance was 7a or higher, RFT was associated with a higher risk of SPIIF. Among those climbers who did bouldering only, this trend was seen even more clearly. Thus, our results suggest that in climbers with a long background in the sport, RFT may prevent finger injuries. On the contrary, in climbers performing at a high level in the early stages of their career, fingerboard training may increase the risk of finger injuries.

To our knowledge, the effects of fingerboard training on injuries have only been studied once before. Auer et al[23] found that fingerboard training first seemed to

Table 3. Self-perceived pain or injury in fingers by years of climbing and level of climbing

Years of climbing	*All*		*Females*		*Males*	
	No. of climbers, N	*Finger injury in the past 6 mo, n (%)*	*No. of climbers, N*	*Finger injury in the past 6 mo, n (%)*	*No. of climbers, N*	*Finger injury in the past 6 mo, n (%)*
<1 y	30	11 (37)	12	3 (25)	18	8 (44)
1–2 y	71	30 (42)	34	13 (38)	37	17 (4)
3–5 y	133	62 (47)	52	22 (42)	81	40 (49)
6–10 y	123	55 (45)	40	22 (55)	83	33 (40)
11 y or more	77	23 (30)	20	5 (25)	57	18 (32)
Level of climbing						
4–6a+	33	10 (30)	25	6 (24)	8	4 (50)
6b–6c+	135	53 (39)	65	26 (40)	70	27 (39)
7a–7b+	186	88 (47)	62	30 (48)	124	58 (47)
7c–	80	30 (38)	6	3 (50)	74	27 (37)

Table 4. Finger injury prevalence and fingerboard training among all respondents who have been climbing for 6 y or more and among men who have been climbing for less than 6 y and whose performance level is 7a or higher

	All respondents who have been climbing for 6 y or more		*Male respondents who have been climbing for less than 6 y and whose performance level is 7a or higher*	
	Finger injury in the past 6 mo, % (n)	*No finger injury in the past 6 mo, % (n)*	*Finger injury in the past 6 mo, % (n)*	*No finger injury in the past 6 mo, % (n)*
Fingerboard training	28% (17)	72% (44)	78% (18)	22% (5)
No fingerboard training	44% (61)	56% (78)	52% (27)	48% (25)
All	39% (78)	61% (122)	60% (45)	40% (30)

increase the injury risk, but after adjusting for age, history of injury, and climbing years, no significant connections were found. As they were studying the relationship between fingerboard training and overall injury risk and had not included an in-depth analysis of climbing years or level of performance, a direct comparison of our findings and their study is not possible.

In previous studies, the rate of finger injuries has varied between 24% during the past 6 mo and 67% during the past 36 mo.[3,5] In our study, with a relatively broad definition for finger pain and injuries, the incidence of SPIIF during the past 6 mo was 42%. Along with the time loss of climbing, we also used the functional loss as suggested by Bahr.[24,25] This together with methodological differences may explain why our results seem high compared with those of previous studies.[3,5,23]

Injury prevention programs in sports, targeting neuromuscular training and its subsets, such as strength training, have been shown to be effective in various sports.[18,21] Strength training has been hypothesized to prevent injuries by strengthening adjacent tissues and thus reducing critical joint loads in addition to muscle strength improvements.[19] Adjacent tissues play a key role in fingers, as there is basically no muscle mass in fingers. Thus, the role of strengthening the adjacent tissues, such as pulleys, tendons, volar plates, and ligaments, should be emphasized in climbing.

Finger loading caused by years of climbing has been associated with adaptation reactions visible on magnetic resonance imaging and radiography, such as thicker flexor tendons, pulleys, and volar plates and increased bone mass density.[7,9-12] In tendons and bones, high loading has been connected to stronger adaptation reactions.[11,13] We found that respondents with a long career in climbing had less SPIIF if they were doing RFT. As fingerboard training is usually done with relatively high loads, we hypothesize that our findings in climbers with more years in the sport are caused by adaptation reactions. Furthermore, in this study, high-level male climbers with shorter careers had a high rate of injuries (Table 4), highlighting the theory that ligaments and tendons require several years to adapt to the high loads in climbing. We showed that RFT was associated with the risk of injuries in this group. The trend was even stronger among those who mainly did bouldering. As bouldering is considered to maximally load fingers, we interpret that fingerboard training on top of constant bouldering can increase the risk of training loads growing too high in individuals whose fingers are not fully adapted to climbing. Therefore, long adaptation processes, overloading risks, and progressive training need to be considered in the injury prevention strategy.

High or rapidly growing training loads are associated with greater injury risk.[26] The size and distance of hand and foot holds, friction, and angle of the wall are the factors influencing the difficulty rating of a climbing route.[11] In our study, most of the men reached the 7a level after 3 to 5 y of climbing. During these years, the risk of SPIIF was also the highest. Performing fingerboard training further increased the risk of SPIIF. If the transition to a higher performance level is fast, we speculate that climbers' fingers are under continuously growing stress that may exceed their capacity to cope. We also suggest that fingerboard training on top of the rapidly rising level of performance may cause excessive strain for most individuals and thus increase the risk of injuries, especially if not applied reasonably.

STRENGTHS AND LIMITATIONS OF THE STUDY

The online survey specified that it concerned finger injuries, which may have caused selection bias as climbers with an injury were probably more likely to take part in the survey. The respondents were not informed about the focus of the study being on possible connections between finger injuries and fingerboard training.

With this kind of research setting, it is impractical to specify whether it is the role of physical adaptations or other factors evolving within one's climbing career that cause different outcomes of fingerboard training for climbers with shorter and longer careers in the sport. Training errors, climbing technique, intensity of training, nutrition, recovery, and presence of coaches or more experienced climbing partners may all influence injury rates. Thus, the results of this study should be interpreted carefully.

Broad definitions of fingerboard training and finger injuries were, at the same time, a weakness and a strength in the study. Not differentiating between strength training and strength endurance training on a fingerboard and not knowing what kind of fingerboard was used may have affected the results.

Looking for all types of finger problems, from little tweaks to total pulley ruptures, gives a good overview of the respondents' self-assessed pain, disabilities, and injuries. In contrast, medical details of the respondents' SPIIF and knowing which fingers were injured and whether or not there was a direct link between RFT and injury could help to specify the underlying causes of the connections found between RFT and SPIIF.

We could not exclude the possibility that climbers with pain or injury in their fingers might have performed less fingerboard training. However, participants were asked about injuries from the past 6-mo period, whereas most respondents had been performing RFT for longer than 7 mo. As previous injuries increase the risk of a new injury,[27] a history of finger problems may influence the willingness to start fingerboard training. That could be one reason why climbers with a long background in the sport who do not perform RFT have more injuries.

Fingerboard training is an important tool for strength training for goal-oriented climbers aiming to progress in the sport. Future studies may benefit from specifying the intensity and frequency of fingerboard training in relation to finger injuries in climbers with different training backgrounds. The role of hand dominance and finger flexor strength training in climbing techniques and in preventing shoulder and elbow injuries would be beneficial to study. In future studies, we suggest that bouldering and lead climbing levels be analyzed separately as they are not completely comparable. In this study, analyzing the highest achieved level in either lead climbing or bouldering allowed a larger number of participants.

Conclusions

In the group of male climbers who had been climbing for less than 6 y and had advanced to a 7a level or higher, SPIIF was common and RFT was connected to more SPIIF. In the group of all climbers with 6 or more climbing years, SPIIF was not as common and RFT was connected to less SPIIF. Fingerboard training increases finger flexor strength and can prevent injuries. However, those advancing in climbing with a relatively short history in the sport should be cautious when adding fingerboard training into their training schedule. Excessive climbing combined with intensive fingerboard training or other training errors may overload fingers and increase the risk of injuries. To conclude, training should be a continuous process during which loading is carefully monitored to result in appropriate tissue adaptations and physiological changes instead of injuries.

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CASE REPORT

An Episode of "Third Person" Phenomenon Involving Somesthetic and Visual Hallucinations in a World-Class Extreme Altitude Climber

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Psychotic symptoms can occur at high altitude. However, most reports are in the mountaineering literature and lack a clear medical assessment and interpretation. Here we report an episode of isolated high-altitude psychosis. It consisted of a "third person" phenomenon involving 2 sensory modalities: somesthetic (felt presence) and visual (the light of 2 flashlights) hallucinations. This episode occurred in a highly experienced climber when he was at an altitude of approximately 7500 m while descending at dusk from the summit of Gasherbrum I (8068 m). The symptoms lasted approximately 3 h and had fully resolved on reaching high camp (7150 m). No other physical or mental symptoms were reported. In addition to hypoxia, a number of other risk factors could have contributed to the occurrence of psychosis in this climber. These included sleep deprivation, exhaustion, dehydration, electrolyte disturbance, reduced visibility, feeling of isolation, and perceived danger. The climber has participated in many extreme altitude expeditions, and neither before nor since this episode has the climber experienced psychotic symptoms.

Keywords: high altitude, hypoxia, mountaineering, phantom presences, psychosis

Introduction

A wide range of psychotic symptoms have been reported at high altitude (HA).[1,2] Common symptoms of psychosis are hallucinations, delusions, and disorganized thoughts or speech.[3] Hallucinations are sensory perceptions occurring in the absence of the respective stimulus. The "third person" phenomenon is a specific form of hallucinations involving the sensed presence of one or more additional persons, a type of somesthetic misperception that can occasionally be accompanied by visual or acoustic hallucinations of the phantom presence.[1,4,5]

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Psychotic symptoms at HA have been described in the mountaineering literature for many decades[6]; however, these reports often lack medical assessment and interpretation, and it has, therefore, been difficult to identify the underlying triggers. A diagnosis of "isolated HA psychosis" can be made if a recent gain in altitude has occurred, there is no previous history of psychosis, symptoms resolve on descent, and there is no underlying medical trigger.[1]

Here, we provide a detailed report of an episode characterized by symptoms of isolated HA psychosis involving a "third person" phenomenon.

Case Report

A 44-y-old Caucasian male, a very experienced professional mountaineer, experienced an episode of psychotic symptoms while descending exhausted helping his climbing partner from the main summit of Gasherbrum I (8068 m). He saw in front of him 2 flashlights moving in

the dark, and he felt a powerful sensation of the presence of 2 people coming to rescue them. He assumed that the lights were downhill at a distance of approximately 300 to 500 m. The perception of 2 "third persons" assured him that they were already safe and encouraged him to continue down the mountain toward the lights. The whole episode lasted approximately 3 h: it started at sunset, approximately 4 h after leaving the summit, when both climbers were still at an altitude of just over 7500 m; continued during the night; and completely disappeared shortly before both reached Camp III (7150 m):

The faint glow of dusk was fading behind the endless ridges and peaks of the Karakoram. We were isolated and exhausted on that dangerous stretch of the mountain, trying to lose altitude while moving like automata, descending very slowly and haltingly through the deep snow. Down the hillside I glimpsed two distant lights, flashing at times, as if they were flashlight bulbs. Suddenly, I noticed an intense presence of two beings approaching us bringing food and drink. At that moment, despite my daze, a great sense of calm came over me. Those unexpected saviors, whose figure I did not perceive at any time, were companions of our same expedition. I was confident of closing the distance, but I felt strange and somewhat confused by the fact that both teams never caught up with each other, although those lights and presences were there, advancing towards us, and we towards them. We continued descending the steep slope of the mountain until I identified the location of our tent, which was sheltered behind a promontory on the slope. In that instant, those mysterious presences and lights, which accompanied me for several hours, vanished forever.

The climber did not experience symptoms suggestive of acute mountain sickness, high-altitude cerebral edema (HACE), migraine, HA pulmonary edema, or an infectious process at any time during the expedition. He had also not ingested stimulant drinks, legal or illegal drugs, or medications; specifically, no dexamethasone was used. However, he reported having slept only 2 to 3 h the night before the summit attempt, and furthermore, he reported that it was one of the most challenging ascents in his entire mountaineering career. He reached the summit very exhausted after 12 h since he had to make his own track through deep snow. Both climbers had barely ingested food and fluids since before beginning their summit attempt. Other than the extreme physical and mental exhaustion, the mountaineer did not report any unusual events during the days and hours before the occurrence of the psychotic symptoms. Mental fatigue could be a consequence of his lack of sleep and mental stress due to the feeling of danger and isolation while helping his exhausted partner to descend and also due to probable severe hypoxemia during his physical overexertion at extreme altitude.

The climber has a track record of outstanding climbing experience, participating in a total of 31 expeditions to the Himalayan and Karakoram ranges, successfully reaching all 14 summits over 8000 m (some of them twice), and completing 3 expeditions in the Arctic and Antarctic regions. He used supplemental oxygen only during his ascent of Mount Everest. The episode that we describe here occurred during his 11th successful summit above 8000 m. He has neither experienced symptoms of a mental disorder prior to or after the episode described nor has he reported suffering from chronic physical diseases or a family history of psychotic disorders. It is also important to point out that the examining physician (EG) had not noted any signs of a personality or other mental disorder during his repeated contacts with the climber.

Discussion

Exposure to hypobaric hypoxia can result in an inadequate oxygen supply to the brain, the most oxygen-dependent organ in the body.[7] While hypoxia alone is known to favor the onset of hallucinations,[8] a range of diseases and environmental factors may also trigger such symptoms. The latter may include infections or HACE; in these cases, psychotic symptoms often occur in the context of delirium.[1,9,10] A combination of environmental and intrinsic factors can also trigger psychotic symptoms during HA exposure in the mountains. This includes social isolation, monotonous activity, dangerous or life-threatening situations, physical or mental exhaustion, dehydration, electrolyte disturbance, sleeplessness, exposure to low temperatures or strong winds, and sensory deprivation, such as reduced visual input.[4,11-16] All these factors were present to some extent in the case we report.

A range of visual hallucinations experienced at HA have been reported, from seeing lights, objects, human figures, and animals to hearing multiple presences speaking. Some of the longest episodes reported in the scientific literature are a case of sustained visual hallucinations of up to 2 d,[9] and another of somesthetic illusions (ie, concerned with bodily sensations) lasting up to 12 h.[4] Among the most common somesthetic hallucinations at HA is the sensation of the presence of a single imaginary person located very close to oneself,[11,17] a duplication of one's own body.[18] A compilation of "third person" phenomena in the mountaineering literature reports that these presences are commonly identified as an

acquaintance or family member, and although the phenomenon seems to be triggered somewhat more frequently during mountain ascents, many cases have also been described during descents, particularly in dangerous situations.[6] Despite the known risk factors for psychosis, an analysis of psychotic episodes occurring at HA from the mountain literature found neither a difference in the occurrence of psychotic episodes during ascent or descent, when alone or in a group, nor an association with danger or snow-blindness.[1] However, starvation was significant in the reported study.

It is important to note that the climber we describe had not taken drugs or medications that could have had an effect on the central nervous system, including corticosteroids that are particularly known to trigger developing psychotic symptoms.[19] Furthermore, the episode described here is the only episode with psychotic symptoms experienced by him, despite having been exposed, before and after the episode, to many dangerous situations at extreme altitude throughout his extensive mountaineering career. This contrasts with a total of 46 hallucinatory events experienced by 7 of 8 world-class extreme altitude climbers.[4] The fact that the described climber experienced only 1 single episode is remarkable because it highlights that apart from hypoxia or genetic factors, which remained constant across the summit attempts above 8000 m, other contributing factors may need to be present.

In one of the largest studies on altitude sickness, hallucinations are present in 3% of subjects with HACE, but no details are given on the exact nature of the hallucinations.[20] In another study, HACE is reported in 32% of cases with psychosis, showing the perceptional disturbances as helpful in 23% and dangerous or frightening in 17%, while the remaining climbers perceived them as neutral.[1] Many of the mountaineers who have experienced the "third person" phenomenon at extreme HA agree that this intensely vivid perception has helped them survive in challenging situations or aided a successful climb,[6,17,21] but an association between psychosis and accidents or near accidents in high mountains has been suggested.[1]

Conclusions

Several stressors probably contributed to triggering the perceptual disturbances experienced by the climber we reported. The case is instructive since it was possible to identify some contributing factors to the psychotic symptoms in hypobaric hypoxia, such as mental and physical exhaustion, darkness, and isolation. The climber had climbed to the same altitude prior to and following the reported episode without any psychotic symptoms. This indicates that, depending on the individual vulnerability, several risk factors may have to accumulate to cause psychotic symptoms at HA.

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