CASE REPORT

Kite Skier's Toe: An Unusual Case of Frostbite

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Frostbite is a well-known occurrence in outdoor winter activity and exploration. We report the first documented case of frostbite associated with kite skiing. Kite skiing is an emerging sport that uses a kite to harness wind power for recreation and to travel long distances on skis. Certain characteristics of this sport may predispose athletes to frostbite injury. The stance required to resist and redirect the force created by the wind and kite puts constant pressure and repetitive trauma on the downwind great toe. This can compromise blood flow and increase risk of cold injury. Future kite skier expeditions should focus on specific prevention methods including properly fitting boots, adequate boot insulation, and frequent rest periods to inspect and warm toes.

Key words: frostbite, kite skiing, Antarctica, cold exposure

Introduction

Two men recently completed a journey crossing Antarctica on skis powered by wind and kites. This form of travel is known as “kite skiing.” The toes of one of the expedition members sustained frostbite injuries during the trip whereas those of the other member did not. The injuries were likely caused by a combination of factors including subzero temperatures, boot selection, repetitive microtrauma, and pressure ischemia unique to kite skiing. Frostbite was first diagnosed on day 38 of the 81-day expedition and was subsequently followed by remote physician consultation using satellite technology. The patient's toes have healed without amputation.

Case Report

A 48-year-old man and a 27-year-old male companion set out on an attempt to cross Antarctica. The team used kites to harness wind power and propel themselves across the ice while on skis (Figure 1). The expedition traveled from the Russian Station of Novo to the Pole of Inaccessibility, the South Pole, and then on to Hercules

Inlet. They set out on November 6, 2011 (S70°51.333 E011°32.992, elevation 649 m [2128 feet]) and completed the expedition on January 23, 2012 (S79°58.370 W079°43.314, elevation 217 m [712 feet]). They averaged 50.6 km/d for 81 days and covered a total of 4100 adjusted kilometers in that time (Figure 2).

Temperatures ranged between -30°C and -45°C . With wind chill and at higher elevations temperatures likely reached as low as -60°C . The expedition started at 649 m (2128 feet), and the team ascended to 2896 m (9500 feet) pulling loads on skis during the first 2 weeks of the trip. For the next 50 days they stayed between 2896 m (9500 feet) and 3658 m (12,000 feet) before starting their descent to sea level on day 81. The sun was present 24 hours a day. After their initial ascent, kites powered 90% of the trip. The kite skiing allowed them to quickly cover large distances. Sastrugi, sharp irregular ridges formed on snow surfaces by wind erosion, dominated the landscape they traveled on.

The subject wore Dynafit ZZero 4 PX-TF Alpine Touring Boots with fiberfill overboots and Rossignol S86 Skis with Dynafit bindings. The fiberfill overboots were insulated with Kevlar and Nomex and had a wind-resistant outer layer. His partner wore Millet Everest mountaineering boots and Rossignol S3 skis. Their sock systems included a thin base layer, a vapor barrier, and a

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Figure 1. Kite skiing in Antarctica.

thick wool layer. Boots were kept loose to allow for improved circulation throughout the day. Both participants were diligent about monitoring their feet for sufficient warmth, rotating socks regularly, and keeping their feet dry. Despite preventive measures, the patient developed numb toes early in the expedition.

On day 22 of the expedition, the subject injured his right big toe. His toenail broke, and the distal toe subsequently became swollen and developed a friction blister. This blister then burst and continued to ooze serosanguinous fluid throughout the coming weeks. The fluid

underwent repeated freezing and thawing, which contributed to cold injury. Initial care was ibuprofen, 800 mg twice daily, and dressing the toe with both antibiotic ointment (Fucidine and polysporin) and medical tape each morning and evening. On day 38, the subject sought medical advice via satellite phone from the physician based at the Union Glacier Camp (D.G.). The subject was also able to e-mail digital photos of the affected toe to aid the consultation (Figures 3–7). The diagnosis was established as a combination of bruising from trauma and frostbite. An additional opinion was requested from a UK expert in frostbite injuries (C.I.). Internet communication was established, and the consultant confirmed the diagnosis of frostbite and postulations were made about the mechanism of injury.

The doctors present in Antarctica, in conjunction with consulting off-site physicians, advised a couple of days of rest to evaluate healing in the temporary absence of further trauma and cold temperatures. There was some concern that continuing the expedition for the remaining 6 weeks would be detrimental for the long-term health of the toe. Evacuation was considered, but with noted injury improvement, the expedition made the decision to continue.

On resuming the expedition, the team made changes to their itinerary and footwear systems. Initially they had

Figure 2. Route taken by kite skiers on the Antarctica 2011–2012 Legacy Transcontinental Expedition.

Figure 3. Initial photograph on day 38 (December 12, 2011) of the expedition.

been traveling in 2-hour increments that were shortened to 1-hour blocks for the remainder of the trip. After each of these travel hours, they released their ski bindings so they could walk and restore circulation to their lower extremities. The subject's partner also traded one boot and accompanying ski setup so that the subject's injured toe had optimal warmth. Given two different foot sizes, they had to modify the inside with felt liners and a different sock system. They documented continued improvement at the site of injury, and on day 53, the Antarctica Pole of Inaccessibility (POI) was reached. This represents a landmark in polar exploration that no previous team had succeeded in reaching without assistance or motorized transportation. Subsequent to reaching the POI, the direction of wind travel changed and pressure was transferred to the left foot. This resulted in the eventual loss of the left great toenail and frostbite on

Figure 4. Toes of the subject on day 46 (December 20, 2011) of the expedition.

Figure 5. Toes of the subject on day 69 (January 12, 2012) of the expedition.

the foot that was previously unaffected. This too was managed by the patient and surveyed by remote medical consultants.

After completion of the expedition, both great toes improved. After several weeks of recovery the toes sloughed necrotic tissue and no bone involvement was suspected. Additional consultation at the Intermountain Burn Center (A.C., S.M.) confirmed that both toes would likely recover without surgical debridement or amputation. The toes eventually healed as predicted (see Figure 7).

Discussion

Frostbite is a well-known consequence of winter activity and exploration. Frostbite occurs when freezing tissue causes direct damage through microcrystal formation and ischemia through microvascular thrombosis. Factors that contribute to frostbite include extreme cold, inadequate or wet clothing, wind chill, and poor circulation

Figure 6. Toes of the subject after return to home (February 9, 2012).

Figure 7. Toes of the subject after further recovery (April 28, 2012).

caused by peripheral vascular disease, diabetes, cramped positions, smoking, and certain medications.¹ It is likely that the prolonged time on one particular track with sustained pressure on the downwind foot causes repeated trauma and pressure ischemia (see [Figure 8](#)). These characteristics, unique to kite skiing, increase the risk of frostbite. In this case, Antarctic subzero temperatures, choice of equipment, and the mechanics of kite skiing contributed to the development of this injury.

Repetitive trauma and poor perfusion secondary to pressure are variables that likely contributed to the skier's injury and appear unique to kite skiing. Inherent to this sport is repeated toe trauma from boot strike during travel. The stance required to resist and redirect the force created by the wind and kite puts excess pressure on the downwind foot ([Figure 8](#): note left foot.). As the down-

wind leg and foot work to set the skis' edge, pressure is transferred to the great toe and can impede blood circulation to the digit. This pressure is constant, in contrast to downhill skiing, which alternates stress evenly between both feet. During the first week of kite skiing, the subject experienced numb toes. This numbness, likely caused by a combination of trauma, pressure ischemia, and cold, represents neuropraxia of small nerves and affected the subject's ability to sense freezing, thus putting him at risk for injury.²

Choice of footwear is crucial in an extremely cold climate. The subject chose a lightweight ski touring boot (Dynafit ZZero 4 PX-TF Alpine Touring Boots). In any expedition, especially an unsupported trip, weight becomes a significant consideration. Lightweight gear implies thinner plastic and liners, which proved insufficient to protect the patient from cold injury despite fiberfill overboots. Mountaineering boots (eg, Millet Everest), although warm, have minimal ankle support, thus making kite skiing more difficult and increasing the risk of ankle trauma and binding malfunction. In this expedition, the partner wearing mountaineering boots did not sustain frostbite injury. Boots that are large enough to support multiple sock layers and warm air trapping, which improves insulation, seem to be critical in this type of expedition.^{2,3} Electric boot warmers are another consideration but require significant battery power, up to 8 batteries a day, and are therefore not feasible on long expeditions. Chemical foot warmers can provide additional external heat, but the extra weight and unpredictable efficacy in extreme cold make these impractical as well. Custom foot beds should be considered as they can

Figure 8. Schematic diagram of kite skiing and toe pressure.

add insulation and help distribute pressure evenly across the foot.

Future kite skiers on long, cold expeditions can prevent cold injury in a number of ways. Boot selection is a key element. A boot that provides adequate insulation, rather than a lightweight boot, is preferred. Soft, entry-level ski boots tend to be warmer and suitable for kite skiing where a more performance-oriented boot may not be necessary. Mountaineering boots also provide warmth but less ankle stability and binding options, making the sport more difficult. Properly fitting boots and multiple sock layers that are kept as dry as possible are essential. Overboots can be added for additional warmth. Regularly changing direction of travel and frequent stops to inspect feet and redistribute circulation into pressure areas are additional measures to reduce the chance of frostbite injury.

The use of satellite communication technology and multiple medical consultations and collaboration between the United Kingdom, the United States, and Antarctica were an asset in this patient's care. Similar services are becoming available worldwide to support teams venturing into austere environments. With ever increasing technologic advances in communication, the ability to receive world-class medical care is becoming as close as the nearest satellite phone.

Conclusions

The forces on each sojourner's feet were similar. Despite good preventive measures, the subject developed frostbite. Footwear and equipment likely made the difference in outcomes. Future kite skier expeditions in cold areas should focus on specific prevention methods including properly fitting boots, adequate boot insulation, and frequent rest periods to inspect and warm cold feet.

Acknowledgments

We would like to thank the patient and his administrative staff for all their help in preparing this article. Photographs courtesy of the patient: Sebastiancopelandadventures.com.

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