WILDERNESS & ENVIRONMENTAL MEDICINE, **26,** 295–304 (2015)

ORIGINAL RESEARCH

Finger and Toe Temperature Responses to Cold After Freezing Cold Injury in Elite Alpinists

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Objective.—To assess whether previous freezing cold injuries (FCI) would affect digit skin temperatures and rewarming rates during a follow-up cold stress test protocol.

Design.—Nonrandomized control trial.

Methods.—Twenty elite alpinists participated; alpinists with previous FCI requiring digit amputations (injured, INJ: n = 10 total, n = 8 male) were compared with ability-matched, uninjured alpinists (control, CON: n = 10, all male). Digit skin temperature was measured using infrared thermography as an index of peripheral digit perfusion after a cold stress test, which consisted of 30 minutes of immersion in 8°C water.

Results.—The INJ alpinists' injured toes were warmer (approximately 6%) than their uninjured toes immediately after cold immersion (95% CI, 0.01°C to 1.00°C; $P = .05$); there were no differences between the rates of rewarming of injured and uninjured toes (INJ, 0.5° ± 0.1°C/min; CON, 0.7° ± 0.3°C/min; $P = .16$). Although the INJ alpinists had colder injured fingers immediately after the 35°C warm bath compared with their own uninjured fingers (32.2° ± 2.0°C vs 34.5° ± 0.5°C; $P = .02$), there were no differences observed between the rates of rewarming of injured and uninjured fingers after cold exposure (INJ, 1.1° ± 0.2°C/min; CON, 1.3° ± 0.5°C/min; $P = .22$).

Conclusions.—Even after FCI that requires digit amputation, there is no evidence of different tissue rates of rewarming between the injured and uninjured fingers or toes of elite alpinists.

Key words: amputation, blood flow, frostbite, mountaineering, trauma, wilderness medicine

Introduction

Of all body regions, fingers and toes are at a greater risk of freezing cold injuries (FCI, ie, frostbite), especially in alpine, subzero environments.[1] Freezing cold injuries of the lower extremities are more frequent than those of the upper extremities.[2,3] Tissue that has sustained frostbite often exhibits immediate functional impairment and sequelae (chronic pain, cold sensitivity, localized osteoporosis) long after the initial incident has occurred. Such affected tissues are therefore anecdotally thought to be predisposed to future cold injury,[4] although evidence-based studies, including follow-up assessments of frostbite, are rare. Indeed, with frostbite that requires amputation, the nonviable tissue is removed, and thus, despite obvious functional impairments, it is not known whether the remaining tissues could be at greater risk for future cold injury, or whether the tissues may remain asymptomatic over time.

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Because frostbite is accidental in nature, accurate incidence rates are difficult to determine with certainty,[3] although individuals with previous cold injuries to upper and lower extremities and those with cold intolerance as a result of hand fractures[5] or after nerve injury[6] represent a sizable clinical population that may be predisposed to repeated, future cold injuries. Reported incidence rates of cold injury can be very high in alpinists, reportedly 37% in that population per year,[1] compared with the cumulative lifetime incidence of frostbite in young Finnish men, also reported to be as high as 44% to 68%.[7] Often, immediate or timely medical attention of frostbite injuries in alpinists is impossible; a 10-year epidemiological study of frostbite in the Karakoram mountain range revealed that only 2% of patients could be evacuated to the nearest hospital within 6 hours of the incident.[3] Indeed, few randomized, controlled studies have been conducted to quantify the incidence, epidemiology, and predisposing factors of frostbite in high altitude alpinist populations. Between 1951 and 2009 there were 6571 mountaineering accidents involving 11,979 people reported to the American Alpine Club within the United States alone,[8] thus constituting a relatively large population that is routinely at risk for future cold injuries.

Rapid hand or foot cooling can induce general sympathetic stimulation, and is often used to investigate subsequent rewarming rates of the fingers or toes.[5,6] Digit skin temperature is well correlated to skin blood flow;[9] it can be quickly and noninvasively measured in conjunction with a cold stress test, although these techniques are rarely used in follow-up cases of clinical frostbite. When exposed to a cold environment (<15°C), skin temperature can rapidly increase in a cyclical manner (hunting response). Indeed, it has been shown that mean skin temperatures and rates of rewarming can be altered after acclimatization to altitude[10] and improved baseline and recovery temperatures after 15 months of military training in the cold,[11] although the "trainability" of fingers and toes to cold exposure per se in laboratory studies has not clearly demonstrated enhanced adaptations to cold.[12,13] These studies have suggested, conversely, that there is an increased injury risk with repeated cold exposure. Therefore, although the literature in cold adaptation is equivocal, cold intolerance is assumed to be related to vascular dysfunction,[14] and measuring temperature responses after cold exposure as a means of characterizing (or indexing) future cold injury is not well established in the clinical literature to date.

One of the simplest and most convenient methods of noninvasively evaluating dynamic changes in cutaneous temperature is via infrared (IR) thermography. IR thermography has been used to clinically assess skin temperatures after a cold test in outdoor manual labourers,[15] circulatory compromise of non-FCI in soldiers[16] and other such varied conditions as diagnosing type 2 diabetes,[17] burn depths,[18] vascular responses after abstinence from smoking,[19] and detecting compressive neuropathies such as carpal tunnel syndrome,[20] traumatic nerve injury,[6] and hand fractures.[5] Indeed, using IR thermography to measure the spontaneous rewarming rate of the hand after cold immersion has been suggested as a useful tool to prospectively identify individuals who are at higher risk of experiencing an FCI.[11] However, no study has attempted to evaluate the functional capabilities of injured alpinists' digit perfusion many years after surgery. Therefore, the purpose of this study was to determine whether elite alpinists with previous frostbite injury that required amputation had significantly different rates of rewarming after a cold stress test when compared with their ability-matched, elite alpinist counterparts. It was hypothesized that 1) digits within the injured alpinist population would be colder than matched controls; 2) the injured alpinists' injured digits would be colder than the digits of their own contralateral, uninjured side; and 3) rates of rewarming would be slower in the injured cohort than in the matched controls for both fingers and toes.

Methods

The protocol of this study was approved by the National Committee for Medical Ethics at the Ministry of Health of the Republic of Slovenia, and it conformed to the Declaration of Helsinki guidelines. Written, informed consent was obtained from each participant before participation in the study. Any identifiable participants have provided their signed consent to publication. Participants were requested to refrain from consuming alcohol and caffeine, and from engaging in exertional activity on the day of testing. All testing was performed in a climate-controlled laboratory environment (between 21° and 23°C, 52% relative humidity) during the northern hemisphere summer (June and July) at the Olympic Sport Centre Planica (Rateče, Slovenia).

STUDY POPULATION

Twenty elite Slovenian alpinists volunteered for this nonrandomized control study. The alpinists were all high altitude climbers with experience on peaks higher than 8000 m. The alpinists were divided into 2 groups: those who had suffered previous FCI that required amputation on either their fingers or toes (injured: INJ), and those who had not sustained any known freezing or non-FCI (control: CON). All alpinists at the time of testing were still actively climbing in high altitude (>4000 m) environments and participating in seasonal expeditions.

COLD STRESS TEST

A cold stress test, defined here as a 30-minute cold-water immersion of the hand or foot, was used to determine rates of tissue temperature changes before, during, and after the cold immersion. Each participant arrived approximately 15 minutes before the testing session began. Participants were dressed in a T-shirt and trousers, with shoes and socks removed, and were seated on a semirecumbent chair for the duration of testing. This particular cold stress test protocol follows methods described elsewhere.[21,22] Briefly, after instrumentation and 5 minutes of baseline recording, participants placed their hand or foot in a thin, plastic bag to avoid their skin