BRIEF REPORT

Nonfreezing Cold Injuries Among Long-Distance Polar Rowers

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Introduction—Nonfreezing cold injury (NFCI) is a peripheral cold injury that occurs when the extremities are exposed to cold temperatures, at or near the freezing point, for sustained periods of time (48–96 h at temperatures of usually around 0 to 6°C with associated wind chill). Although NFCI often goes unreported and may be underdiagnosed, it is a cause of significant morbidity in those working in cold conditions, particularly those in the military. Thus, further research into the prevention, recognition, and treatment of NFCI is warranted.

Methods—The height, body weight, and body composition of 6 rowers taking part in 1 or 2 legs of the 2017 Polar Row expedition were measured. The weather conditions of the 2 legs of the journey were recorded, and symptoms relating to NFCI were documented.

Results—All incidences of NFCI occurred during Leg 2 of the expedition, which was colder and wetter. Of the Leg 2 rowers, those who developed NFCI had a trend toward higher pre-row body weight and body mass index and a trends toward losing more weight and body water relative to those who did not.

Conclusions—The main factor contributing to the incidence of NFCI appeared to be weather; NFCI only occurred during the colder and wetter leg of the expedition. We also tentatively suggest that nutrition and dehydration may be linked to the incidence of NFCI as predisposing factors. More work, with sample sizes greater than those reported here, is required to investigate these associations to further characterize risk factors.

Keywords: NFCI, ocean rowing, polar expedition, dehydration

Introduction

Nonfreezing cold injury (NFCI) is a general term that includes trench foot and its nautical equivalent, immersion foot. NFCI involves injury to the soft tissues, nerves, and vasculature of distal extremities. The cause is prolonged exposure to wet, cold (but nonfreezing; generally, 0–15°C or 32–59°F) conditions. Most often feet are involved, but the condition can affect any dependent body part, including hands.¹

NFCI typically follows a time course described by the following stages. NFCI may result from vascular stasis

and ischemia (stage 1—during exposure), followed by a prehyperemic stage (stage 2) during which the feet remain numb and feel heavy. This is followed by the hyperemia stage (stage 3), wherein the feet rapidly become hot and flushed with bounding pulses. During the final stage (stage 4), the feet return to normal appearance, but there is usually persistent numbness and pain^{2,3} that is associated with histological or clinical evidence of nerve damage.^{4,5}

Most cases of NFCI involve the feet or the hands. Clinically, NFCI is often insidious in onset and can be difficult to recognize and challenging to treat² (stage 1). The cardinal symptom during exposure is numbness; upon rewarming (stage 2), an initial pain-free period is followed by skin erythema, edema, and a neuropathic, burning pain (Stage 3). There are often few clinical signs on examination after the posthyperemic stage has occurred (stage 4). The pain persists; it can last for many months or years and may be permanent after initial injury. The neuropathic pain is

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nonresponsive to opiates, but other drug classes, such as tricyclic antidepressants, are often effective. Delaying the start of this treatment increases the risk of development of severe chronic pain that is resistant to treatment. There may be long-term sequelae depending on the severity of the injury, and there is often increased sensitivity to cold after the injury; in severe cases, this sensitivity may leave individuals unable to work outside. Occasionally, there may be persistent edema and hyperhidrosis, leading to a susceptibility to fungal infections, ulceration, and tissue loss.^{2,6}

People of Afro-Caribbean ethnicity and those with previous cold weather injury have an increased susceptibility to NFCI,^{7,8} although smoking is not considered to be a risk factor.⁹ Although dehydration has been shown to reduce skin temperatures during laboratory-based cold exposure, it has not yet been proven as a risk factor in NFCI.¹⁰

THE POLAR ROW EXPEDITION

The Polar Row was a 2-part ocean rowing expedition beginning July 2017 and covering 1251 NM (2361 km; 1440 mi).

The first leg of the expedition included 5 male rowers who departed Tromsø, Norway, and crossed the Norwegian Sea to Longyearbyen (Svalbard). Excluding a 30-h stop in Hornsund (Svalbard), the total time spent at sea was 8 d and 20 h. Three of the crew left the expedition at this stage and were replaced by 4 new rowers. Leg 2 of the expedition included 6 male, Caucasian rowers. The crew departed Longyearbyen and headed north, reaching the permanent ice shelf at latitude N 79°55'28.5708 and longitude E 10°26'58.3548 after 42 h of rowing. The crew then changed course and headed south-southwest across the Greenland Sea, arriving in Jan Mayen after 13 d and 20 h at sea. The crew then transferred to accommodations and had hot showers within 2 h. See Table 1 for a summary of conditions at sea.

The crew used a continuous 90-min shift pattern; 90 min of rowing, followed by 90 min of nonrowing time (used for *ad libitum* eating, washing, going to the bathroom, and/or sleeping). During the rest periods, the rowers sheltered in small, sealed cabins at either end of the boat.

The rowers wore similar kit: sweat-wicking base layers, fleece mid-layers, and a waterproof outer layer. Waterproof gloves, rubber boots, and thick waterproof socks (featuring a hydrophobic membrane and providing no compression) were also worn by all crew members.

Methods

As part of the European Research Council-funded ADaPT Project (Adaptation, Dispersal and Phenotype, University of Cambridge, UK), a series of anthropological measurements were taken from Leg 2 rowers both before and after the expedition. Ethical approval for the data collection leading to this brief report was granted by the University of Cambridge human biology research ethics committee.

Height was measured using a stadiometer (Seca, Hamburg, Germany), using standardized technique.¹¹ Body mass was measured using scales accurate to 0.1 kg (Seca). Body composition was measured using bioelectric impedance analysis (BodyStat Quadscan4000, Isle of Man). This method was chosen for its simplicity, speed, precision, and suitability for measuring short-term changes in individuals.¹²

STATISTICS

Independent samples *t*-tests were performed to compare NFCI and non-NFCI groups. Analyses were performed using SPSS v21, and significance was set at $P < 0.05$.

Results

This dataset allowed for a comparison of the rowers who did and did not experience NFCI. See Tables 2 and 3 for a comparison of their descriptive characteristics, both pre- and post-row.

Rowers who would go on to experience NFCI had a trend toward being taller (NFCI: $M = 189$ cm, $SD = 8$ cm; non-NFCI $M = 187$ cm, $SD = 4$ cm), heavier (NFCI: $M = 92.3$ kg, $SD = 6.5$ kg; non-NFCI $M = 84.8$ kg, $SD = 6.6$ kg), having higher body mass index (NFCI: $M = 25.7$ kg·m⁻², $SD = 1.2$ kg·m⁻²; non-NFCI: $M = 24.2$ kg·m⁻², $SD = 1.5$ kg·m⁻²), and having higher fat percentage (NFCI: $M = 14.7\%$, $SD = 0.9\%$; non-NFCI: $M = 13.4\%$, $SD = 1.7\%$) and

Table 1. Summary of the conditions at sea during Legs 1 and 2

	Route	Duration	Air temperature (°C)	Humidity (%)	Waves
Leg 1	Tromsø (Norway) to Longyearbyen (Svalbard)	8 d 20 h	6–9	75–85	Smaller (approximately 1–2 m), not breaking onto the deck
Leg 2	Longyearbyen to Jan Mayen	13 d 20 h	1–2	98–99	Larger (approximately 5 m), breaking onto the deck

Table 2. Pre-row descriptive characteristics of NFCI vs non-NFCI rowers

	NFCI-1 Leg 2	NFCI-2 Leg 2	NFCI-3 Leg 2	Mean (SD) (n=3)	Non-NFCI-1 Leg 2	Non-NFCI-2 Legs 1 and 2	Non-NFCI-3 Legs 1 and 2	Mean (SD) (n=3)	Comparison of NFCI to non-NFCI	
									t	P
Age (y)	30	23	33	29 (5.1)	30	42	37	36.3 (6.0)	-1.677	0.169
Height (cm)	188	182	198	189 (8)	192	185	184	187 (4.4)	0.440	0.683
Weight (kg)	95.2	84.8	96.8	92.3 (6.5)	90.2	77.4	86.8	84.8 (6.6)	1.391	0.237
BMI (kg·m ⁻²)	27.1	25.6	24.7	25.8 (1.2)	24.5	22.6	25.6	24.2 (1.5)	1.397	0.235
Fat (%)	15.1	13.6	15.3	14.7 (0.9)	12.3	12.5	15.4	12.3 (1.7)	1.115	0.327
Fat mass (kg)	14.4	11.5	14.8	13.6 (1.8)	11.1	9.7	13.4	11.4 (1.9)	1.446	0.222
Lean mass (%)	84.9	86.4	84.7	85.3 (0.9)	87.7	87.5	84.6	86.6 (1.7)	-1.115	0.327
Lean mass (kg)	80.8	73.3	82.0	78.7 (4.7)	79.1	67.7	73.4	73.4 (5.7)	1.241	0.282
Weight change (kg)	-12.8	-1.0	-8.3	-7.7 (6.2)	-5.0	+1.8	-5.4	-3.1 (4.8)	-1.020	0.366
Weight change (%)	-13.4	-1.2	-8.6	-7.4 (6.0)	-5.5	+2.3	-6.2	-2.9 (4.0)	-1.083	0.3404

NFCI, nonfreezing cold injury.

fat mass (NFCI: M=13.6 kg, SD=1.8 kg; non-NFCI: M=11.4 kg SD=1.9 kg) before departure than non-NFCI rowers. Although NFCI rowers had had a trend toward higher absolute lean mass (NFCI: M=78.7 kg, SD=4.7 kg; non-NFCI: M=73.4 kg, SD=5.7 kg), lean mass percentage was similar (NFCI: M=85.3%, SD=4.7%; non-NFCI: M=86.6%, SD=5.7%). These differences did not achieve statistical significance (Table 2).

During the row, rowers who experienced NFCI tended to lose more weight (absolute weight [NFCI: M=7.4 kg, SD=6.0 kg; non-NFCI M=2.9 kg, SD=4.0 kg]; as a percentage of starting weight [NFCI: M=7.7% g, SD=6.2%; non-NFCI: M=3.1%, SD=4.8%]) than rowers who did not. These results were not statistically significant (Table 2). Within Leg 2, all rowers followed the same shift patterns and consequently rowed the same number of shifts. Retrospective interviews revealed that NFCI rowers ate considerably less food per day than rowers who did not experience NFCI.

NFCI rowers had a trend toward losing more body water during the row (mean of approximately 6.0 kg) compared to non-NFCI rowers (mean of approximately 2.8 kg) (estimated from weight gain in 24 h after arrival in Jan Mayen; all rowers were given the same meals in this 24-h period). These differences did not achieve statistical significance.

CASE STUDIES

Each of the 3 NFCI cases were nonsmoking Caucasian males rowing only Leg 2. None had any previous prolonged cold weather exposure or cold weather injuries. Patients 1 (30-y-old) and 2 (33-y-old) had medical histories of asthma (treated with a budesonide/formoterol inhaler and a fluticasone/salmeterol inhaler, respectively), and Patient 3 (23-y-old) had no medical history/medications. All rowers described their feet becoming cold and wet early in the expedition, which they were unable to rectify. Consistent with stage 1 of the time course of changes previously described,⁷ the rowers then developed tingling and numbness in their feet.

Upon arriving and rewarming in Jan Mayen, the tingling and numbness continued, accompanied by difficulty maintaining balance while walking (consistent with Stage 2).⁷ Within 48 h, intense pain developed in the feet and toes bilaterally. The pain was described as “throbbing,” “incapacitating/excruciating,” “constant and intensifying in waves,” making it “painful to walk and very difficult to sleep.”

Patients 1 and 2

Paracetamol and codeine, the only painkillers available, failed to relieve the pain. Amitriptyline would have been

Table 3. Post-row differences in NFCI vs non-NFCI rowers

	NFCI-1	NFCI-2	NFCI-3	Mean (SD) (n=3)	Non- NFCI-1	Non- NFCI-2 ^a	Non- NFCI-3 ^a	Mean (SD) (n=3)	Comparison of NFCI to non-NFCI	
									<i>t</i>	<i>P</i>
Weight (kg)	82.4	83.8	88.5	84.9 (3.2)	85.2	79.2	81.4	81.9 (3.0)	1.166	0.308
BMI (kg·m ⁻²)	23.3	25.3	22.6	23.7 (1.4)	23.1	23.1	24.0	23.4 (0.5)	0.341	0.750

NFCI, nonfreezing cold injury.

^a Denotes rower who rowed in both legs.

the preferred first option, but it was not available. On Day 12, both started taking amitriptyline, increasing to 100 mg once daily over 3 d. The pain was rapidly alleviated for Patient 1. He continued this dose for 3 wk before gradually reducing and stopping a week later; he remained pain-free. Approximately 6 wk later, he had ongoing tingling and reduced sensation in his great toes bilaterally, as well as increased cold sensitivity. Amitriptyline reduced the pain to “manageable” levels for Patient 2 for 2 wk, at which point he stopped taking amitriptyline due to side effects. Two months later the pain was reduced, but the tips of his toes had constant pins and needles, and this persisted for about 1 y.

Approximately 16 mo later, neither Patient 1 nor 2 had any ongoing pain, and both had regained normal sensation. Although Patient 1 experienced no increased cold sensitivity, this persisted for Patient 2, as well as daily paresthesia when outside.

Patient 3

Paracetamol and codeine provided a mild improvement in pain levels, and pain had fully resolved by Day 16. His feet were swollen with dry peeling skin until approximately Day 12. The numbness remained initially, with pins and needles developing around Day 7. Some sensation began to return on Day 12. It took 6 wk for sensation to return to the majority of his feet and toes, except for the tips of some of his toes, which remained numb for longer. Although Patient 3 displayed some features consistent with warm water immersion (eg, peeling skin), the temperatures to which the patient was exposed were not consistent with warm water immersion (15–32°C).¹

Approximately 16 mo later, there was no ongoing pain and no increased cold sensitivity. The sensation had fully returned to normal except for a small patch (1 cm diameter) on the second toe of his left foot, which remains numb.

Discussion

COMPARISON OF NFCI VS NON-NFCI PATIENTS

All cases of NFCI occurred during Leg 2. This was consistent with previous reports that having cold and wet

extremities for a sustained period of time is a key risk factor for NFCI.^{7,13,14} The non-NFCI group had no foot symptoms after rewarming on land, except for 1 member (who rowed both Leg 1 and Leg 2) who had mild foot paresthesia for a short period of time. He had no pain or persisting neurology, so he did not meet the diagnosis of NFCI.

Leg 1 vs Leg 2 environmental conditions

During Leg 1 of the expedition, on-board instruments indicated temperatures of 6 to 9°C and 75 to 85% humidity, and the waves were relatively small (approximately 1–2 m). During Leg 2, which was 5 d longer than Leg 1, the air temperature fell to 1 to 2°C and humidity rose to 98 to 99%. Athlete-perceived wind strength and sea swell increased, with waves growing to approximately 5 m and regularly washing over the deck and drenching the rowers. The cabins grew damp; the walls and ceiling dripped with condensation, and sleeping bags became sodden. As a result, Leg 2 rowers were often unable get warm and dry between shifts. The severe conditions during Leg 2, which led to rowers being unable to dry their sleeping bags and feet, were unforeseen.

Critical comparison of NFCI and non-NFCI rowers from Leg 2

The data collected here identified no statistically significant differences between the NFCI and non-NFCI rowers. However, the trends observed suggest that it is possible that a larger dataset may reveal differences. Before departure, rowers who would go on to experience NFCI tended to be taller (slightly), to be heavier, to have more body fat, and to be more muscular (higher muscle mass, but a similar muscle percentage) than rowers who would remain NFCI-free. These observations are consistent with recently published data observing a trend of higher body mass indices in military personnel with NFCIs than those without.¹⁵ The magnitude of the recorded differences was small.

The data revealed no statistically significant differences in weight loss between NFCI and non-NFCI rowers during Leg 2. However, during Leg 2 the rowers

who experienced NFCI tended to lose more weight. A larger sample size may or may not have revealed significant differences. All rowers followed the same shift patterns and consequently rowed the same number of shifts. Variation in relative effort levels between rowers was expected to be small. Retrospective interviews suggest that rowers who experienced NFCI ate appreciably less food during the row than rowers who did not experience NFCI. No quantitative data concerning food consumption were collected during the expedition. We speculate that it is possible that statistically significant differences in calorie intake between the 2 groups may have existed, but we emphasize the need for further investigation. Because the thermal effect of food is proportional to meal size,¹⁶ rowers who consumed more food would have benefited from greater heat generation as a byproduct of the digestive process (all rowers consumed the same dehydrated meals, but they differed in the quantities they ate). It is possible that this contributed to the differential incidence of NFCIs within the crew.

NFCI rowers lost more body water during the row (approximately 6.0 kg) compared to non-NFCI rowers (approximately 2.8 kg) (estimated from weight gain in 24 h after arrival in Jan Mayen; all rowers were given the same meals in this 24-h period). Weight gain within the first 24 h of arrival in Jan Mayen reflects previous loss of body water, suggesting that NFCI rowers had a lower hydration status compared to non-NFCI rowers. It is possible, therefore, that there may be an association between hydration status and NFCI risk, with increased hydration reducing the risk of NFCI. This is in contrast to the findings of a recent military-based case series, which found that self-reported dehydration was not a risk factor for NFCI.⁹

LIMITATIONS

The sample size for this report is small. This was a reflection of the crew size for the Polar Row expedition. Measurement of fluid and food intake during the expedition would have been useful to analyze in more depth whether rowers who experienced NFCI drank and ate less than those who did not. Furthermore, a direct comparison between the conditions of Legs 1 and 2 and subsequent NFCI risk is complicated by the different durations.

Conclusions

Here we have described, for the first time, cases of NFCI arising from long-distance ocean rowing activity in a cold-wet environment. We conclude that during this expedition, weather conditions appeared to be the primary factor contributing to the incidence of NFCI. Along with the

degree of coldness and wetness of the environment, we tentatively suggest that inadequate nutrition and dehydration may be linked to the incidence of NFCI as predisposing factors. More work, with sample sizes greater than those reported here, is required to investigate these associations to further characterize risk factors.

The authors would like to note that the motivation for this expedition was to set new world records for exploration, and this was completely independent of any data collection.

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