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Research Article

Short Term Sensory and Cutaneous Vascular Responses to Cold Water Immersion in Patients with Distal Radius Fracture (DRF)

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Abstract

Study Design: Repeated Measures.

Objectives: To determine the short term impact of cold water immersion on sensory and vascular functions in patients with Distal Radius Fracture (DRF) and compare responses in the injured and uninjured hands.

Background: Cold exposure is used to assess neurovascular function. Cold is also used as therapeutic agent to reduce pain and swelling. There is a scarcity of trials that have looked at the impact of cold exposure in patients with DRF.

Methods: Twenty patients with DRF, aged 18 to 65 yrs. were recruited after cast removal. All patients underwent Immersion in Cold water Evaluation (ICE) which consisted of 5 min of hand immersion in water at 12°C. Skin Blood Flow (SBF) in hands, Skin Temperature (S Temp.) in index and little fingers and sensory Perception Thresholds (sPT) at 2000Hz (for Aβ fiber) and 5 Hz (for C fiber) were obtained from ring finger, before ICE, immediately after (0 min, 1 min) and 10 min later. Differences were analyzed using repeated measures.

Results: In the DRF hand, SBF increased immediately (Mean Difference = -42.2 A.U), at 1 min (-35 A.U) and 10 min after ICE (-1 A.U). Skin Temp. In index and little fingers decreased immediately after ICE (9.9°C and 9.1° C) and did not return to baseline by 10 min (4°C and 4.1°C). ICE had no effect on sPT at 5 Hz ($p>0.05$). There was no difference between the DRF and uninjured hand on all measures($p>0.05$) except for the sPT at 2000Hz, which remained high on the DRF side for up to 10 min (-1.8 m. A).

Conclusion: Normal cold responses consistent with 'hunting reaction' were observed after ICE in both hands. Aβ fibers on DRF side became less sensitive after ICE. These findings suggest that a brief immersion in cold water does not produce any adverse events associated with cold exposure.

Introduction

Distal Radius Fracture (DRF) can occur after a fall on an outstretched hand and is one of the most common fractures (in females and older population) [1-3] seen by orthopedic surgeons with an incidence of 195.2/100,000 persons per year [4,5]. DRF can result in an increased morbidity, with long-term functional impairment, pain, and deformity [1,6-9]. Complications (N=275 cohorts) such as Reflex Sympathetic Dystrophy (RSD) (20%), median (22%) and radial (11%) nerve compression and tendonitis (14%) [10] after DRF are often thought to be either missed or overlooked by the treating therapist [11]. Injury to the peripheral vasculature, defective vasoregulation, and nerve injury have been suggested as possible contributors to Cold Intolerance (CI) [2,12-15]. Cold intolerance is an abnormal pain after exposure to mild or severe cold, with or without discoloration, numbness, weakness, or stiffness of the hand and fingers [13,16-19]. Patients commonly report CI after hand fractures, [19] that may arise within the initial months or may have a delayed manifestation, depending on the seasonal nature of the injury [16,18,20,21]. The pathophysiology of CI is still unclear [16]. However, it is postulated that post-traumatic CI has both vascular and neural etiology among other contributing causes [22,23].

When neurovascular dysfunction exists in hands, cutaneous thermoregulation, nutritional blood flow, and autonomic functions may become impaired [24,25]. Cryotherapy is one of the

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most frequent interventions provided by therapists (90%) during the mobilization phase after DRF [26]. It has also been shown to effectively reduce pain and swelling in DRF after the cast removal [27], however if an underlying neurovascular dysfunction or complication exists, then it may be contraindicated for patients to continue treatments with thermal agents or cold modalities. In addition to this, cold intolerance as reported earlier in patients with reflex sympathetic dystrophy [28], median and ulnar nerve injuries [15,29] and hand fractures can be severely disabling [12,30] and may affect their quality of life. Hence, quantitative measurements and cold provocation test [20,23,29,31,32] that are sensitive to changes in peripheral blood flow, thermoregulation and autonomic control may be important in detecting cold intolerance and neurovascular dysfunction in the hand after injury [20,21,23].

Immersion in Cold Water Evaluation (ICE) is a simple and reliable objective cold provocation measure to assess cold responses, peripheral blood flow and temperature recovery in the hand [23,31]. Sometimes, after injury the symptoms of pain due to vascular insufficiency may mimic neurologic conditions [33-37]. Previous reports on the Immersion in cold water evaluation used only skin temperature for the evaluation of thermoregulatory responses [21,23], but did not include neural and vascular measures [25,38,39]. Hand function reflects through the integration of all systems and is thought to be affected by decreased blood flow, cold hands, and loss of sensation. Hence, using baseline sensory, vascular, sympathetic and temperature responses to assess the injured and uninjured hand would be advisable to assist with early detection and monitoring of neurovascular function at important timeline (6 weeks post fracture) during the rehabilitation of DRF. This may also help to plan or modify the future care.

There is also a scarcity of published trials that have looked at the impact of cold exposure on sensory and vascular functions in patients with DRF after cast removal. Hence, the specific aim of this study is to determine whether a brief exposure to cold water immersion using ICE protocol will alter skin blood flow, skin temperature and sensation differently between the affected and unaffected hands of patients with DRF. These evaluations might also inform our understanding about the potential mechanisms behind the therapeutic effect of cold water immersion in DRF.

Methods

Participants

A sample size of 20 was considered for this research. The number needed to detect a moderate effect size for this study (ES r=0.50; two-tailed $\alpha = 0.05$; 80% power) was based on Cohen's criteria [40]. Statistical significance was considered if $p<0.05$.

Patients with DRF were recruited by the treating surgeon or therapist during the sixth week post fracture at the time of cast removal based on the eligibility criteria given in Table 1. Testing was done in the Hand and Upper Limb Research Lab. This study was approved by the Western University Research Ethics Board. All participants read the letter of information, had their questions answered, and signed a consent form prior to participation in this study.

Instrumentation

Immersion in Cold Water Evaluation (ICE) (Traynor and Macdermid 2008) [23]:

ICE is a reliable, objective measure of cold response to assess cold intolerance in hands after injury. This protocol examines peripheral blood flow and the associated temperature recovery. A cold-provocation test is initiated by immersing hands in cold water maintained at a temperature of 12°C (±1°C) for 5 min. and the digital temperatures in the index and little fingers are measured using an infrared skin thermometer during the recovery period. All tests are performed with the patient seated comfortably in a thermo-neutral environment (20°C ± 2°C) [23].

Table 1: Shows inclusion and exclusion criteria used to recruit patients.

Inclusion Criteria	Exclusion Criteria
Injured hand:	Skin infection, open wound
Age 18 to 65 yrs.	Pregnancy
Male & female	Pacemaker/ monitoring device
Stable DRF	Malignancy
Closed reduction	Confirmed reflex sympathetic dystrophy
No therapy at least an hour before test	Inflammatory arthritis
No other injury or disease to the neck, shoulder, elbow, wrist, or hand within past year	Peripheral vascular disease
Uninjured hand:	Previous fractures, revision surgeries, complex fractures with neurovascular injuries
No recent injury or disease to neck, shoulder, elbow, wrist, or hand within the past year.	Autoimmune disorders
	Hypertension, Cardiac failure
	Diabetes
	Internal haemorrhages
	Deficits in sensation in the area to be treated (sensory test to identify sharp and dull sensation; hot or cold)
	Deficit in circulation (Digital patency test for fingers)
	Inability to understand instructions.
	Local hot or cold sensitivity
	Cold adverse reactions

TiVi (Tissue Viability Imager) 600 polarization spectroscopy camera (version 7.4 Wheels Bridge AB, Linköping, Sweden):

The TiVi is a reliable, [41] valid [42,43] and sensitive [44] device used for a high-resolution instantaneous imaging of Red Blood Cell (RBC) concentration in human dermal tissue (to a depth of 400-500 micrometers) [43]. This digital camera (Canon Rebel EOS model 450D, Japan) has shown many uses in drug development, burn investigations, pressure studies, and general research maneuvers due to the ease of use, portability, and low cost [43, 45].

Participants were required to keep their shoulder in neutral, elbow in 90° flexion; forearm (s) supinated and placed somewhat lower than the heart. An outline was drawn to standardize hand position. The camera was positioned at a distance of 30 cm from the participant's hand. One photo was taken every 5 seconds (12 photos / min) which was then uploaded into the attached computer. For each participant, one image at baseline and at each follow up points (0 min, 1 min and 10 min after Immersion in cold water evaluation; with 4 images/hand) were selected for image analysis from the computer. Regions of interest were selected and cropped over the immersed area up to 5cm proximal to the ulnar styloid process. Later these cropped images were used for further statistical analysis.

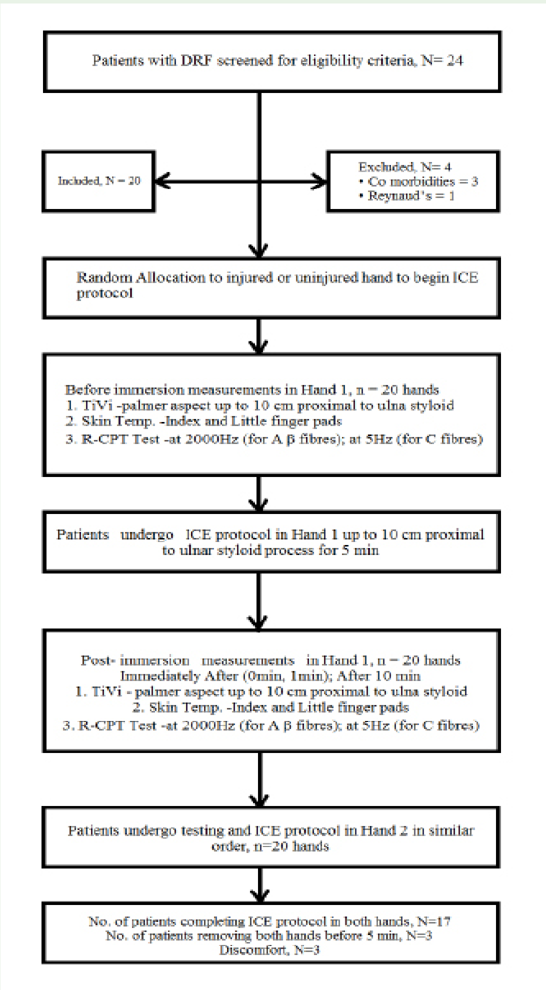

Figure 1: Shows flow diagram of the study protocol.

Neurometer ® CPT/C device (Neurotron Inc., Baltimore, USA)

The Neurometer evaluates sensory nerve conduction (Current Perception Threshold of Aβ, Aδ and C fibers) from the periphery to the brain and has been shown to detect, screen and diagnose the abnormalities of peripheral nervous system [37,46]. It has been shown to be a reliable and valid measure in the evaluation of mechanical neck disorders [47], and found to be specific and sensitive in the examination of carpal tunnel syndrome [47,48]. A frequency of 2000 Hz is used to stimulate the large myelinated Aβ fibers (for touch, pressure); a 250Hz to stimulate myelinated Aδ fibers (mechanoreceptive, fast pain, pressure, temperature), while a frequency of 5 Hz is used to stimulate the small unmyelinated C-polymodal nociceptive fibers (for slow pain, temperature, post ganglionic sympathetic fibers) [37, 46].

Ranged CPT (R-CPT) is a rapid sensory Perception Threshold (sPT) test in the Neurometer which is typically used to confirm or rule out sensory involvement in large samples such as screening [35,37]. In R-CPT, each frequency is repeated several times to ensure accuracy and reproducibility [37]. The Neurometer reports values (R-CPT levels) as, the normal range (6-13), hyperesthesia (1-5), and hypoesthesia (14-25) [35,37]. R-CPT was tested at two frequencies in this study (2000Hz and 5Hz) to target two different nerve fiber types. To begin 2000 Hz stimulation, the skin was cleaned with a skin paste and then the 1 cm gold electrodes coated with small amount of gel were attached to the ring finger with an adhesive tape. Then the participants were asked to press and hold the red "Test cycle" button on the remote control box and release it as soon as they begin to feel the tingling or buzzing sensation. The machine records the response when the button is released by the patient and the same process is repeated 7-10 times until a score is displayed. In total three consecutive scores were obtained at 2000Hz. The same procedure was repeated at 5Hz. These test cycles end automatically after few repetitions (7-10 times) and the Neurometer displays score for 5Hz [35,37].

Study Protocol

Hands of participants were assigned by concealed random allocation using sealed envelopes to indicate which of the two hands would be tested first. Testing was completed in two hands one after the other on same day according to the protocol shown in Figure 1. All the assessments and testing were provided by one physiotherapist.

Subjects were required to acclimatize to the testing room temperature upon arrival for 15 min. They were first measured on Tissue Viability imager (TiVi) over the palmar aspects up-to 10 cm proximal to ulnar styloid process, then Skin Temperature (S Temp.) was recorded from index and little finger pads using King's infrared thermometer, and this was followed by Ranged current perception threshold test (R-CPT) measured from the tip of ring finger (median and ulnar nerve, dermatome C7, C8) to record sensory Perception Thresholds (sPT) at 2000Hz (Aβ fibers) and 5Hz (C fibers) before starting cold water immersion. The participant subsequently underwent Immersion in Cold water Evaluation (ICE) protocol as described by Traynor and Macdermid [23]. Following a 5 min Period of Immersion (POI), the forearm and hand were quickly pat-dried and then skin blood flow, S Temp and R- CPT were measured. The TiVi measurements were taken immediately following (0 min), 1 min following and 10 min following the POI, whereas R-CPT was measured at 1 min following and 10 min following the POI. Skin Temperature was measured immediately (0 min) and 10 min following POI. The delay between the removal of hands from the water and start of the recordings on the three measures was less than 3 min. TiVi took 12 photos for 1 min (0 min to 1 min), Skin Temperature was recorded during the 5 second gap in TiVi, and R-CPT was initiated at the end of TiVi. The protocol was repeated on the subject's opposite hand for comparison in similar order.

TiVi software was used to calculate the mean blood flow (A.U.) over the area of immersion in both hands. The sensory perception thresholds obtained from R-CPT test at 2000Hz and 5Hz (m.A.) were recorded directly from the digital display of the Neurometer onto a separate data collection sheet along with the temperature (°C) readings.

Data Analysis

General Linear Model, repeated measures (using SPSS version 20, IBM Inc.) was used to determine if each participant's injured and uninjured hand had different measures of skin blood flow (RBC concentration), sensory perception threshold, and skin temperature at baseline, immediately after the period of immersion (Immersion in cold water evaluation) and then 10 min following the period of immersion. A 2 × 4 (hand × time) design was used to assess changes in skin blood flow, and a 2 × 3 (hand × time) design was used to assess changes in skin temperature and sensory perception thresholds at 2000 Hz and 5 Hz (Aβ, C fibers) for the injured and uninjured hands. Interactions were examined for significance between hand and time. Post hoc analyses were performed using Bonferroni correction, wherever necessary. Pair -wise comparisons were used to perform within-group comparisons wherever needed. Significance level was set at $p<0.05$ level.

Table 2: Shows participant demographics characteristics.

Age in yrs. (mean± SD)	52 ± 12.2
Gender:	
Females, n (%)	18 (90%)
Males, n (%)	2(10%)
Side of injury:	
Right, n (%)	10(50%)
Left, n (%)	10(50%)
Type of Injury:	
Fall n (%)	18 (90%)
Others (%)	2(10%)

Abbreviations: SD= Standard Deviation;
n = number of patients; % = Percentage of Patient

Results

Twenty patients with DRF were recruited after cast removal between November 2012 to May 2013. Table 2 shows the demographic characteristics of the patients. Table values indicate that majority of the participants were females (n=18) and those who had a fall on an outstretched hand (n=18). No data points were missing. Table 3 shows means, standard deviation and 95% confidence intervals obtained from the General Linear Models (Repeated Measures) to assess the changes in skin blood flow, skin temperature and sensory perception thresholds at 2000Hz and 5Hz. Seventeen participants volunteered to report that they felt good during cold water immersion on their injured side. No long-term discomfort was reported.

In the DRF hand, Immersion in cold water evaluation increased skin blood flow from baseline to immediately after the POI (0 min) (p=.002), then remained high for over a minute (p=.00) and returned to pre-exposure levels by 10 min (p=.45). Post hoc comparisons

Table 3: Shows outcome data for the injured and uninjured hand on Skin Blood Flow, Skin Temperature, Sensory Perception Threshold*

	Normal side (n=20 hands)	***DRF side (n=20 hands)***
Skin blood flow (0-400 A.U)		
Baseline	82±7.5(79,86)	82±9.2(78,87)
Post 0 min	106±26.0 (94,118)	124±34.6(108,141)
Post 1min	104±25.0 (92,116)	118±32.8(102,134)
Post 10 min	84±8.9(80,88)	83±8.4(79,87)
Skin temperature (Index) °C		
Baseline	31.9±3.0 (30.4, 33.3)	31.6±3.1(30.2, 33.2)
Post 1min	22.2 ±5.9 (19.4, 25.0)	21.7±5.1(19.3, 24.1)
Post 10 min	27.2± 6.7(24.0, 30.3)	27.6±5.9(24.8, 30.4)
Skin temperature (little) °C		
Baseline	32.5±2.9 (31.0, 33.9)	32.0±3.1 (30.6, 33.5)
Post 1 min	22.2±5.1 (19.7, 24.0)	23.0±5.8(20.3, 25.7)
Post 10 min	27.4±6.1 (24.5, 30.0)	28.0±5.9(25.2, 30.7)
R-CPT at 2000Hz (0-24 m.A)		
Baseline	8.4±2.1(7.4, 9.4)	8.9±1.9(8.0, 9.8)
Post 1 min	9.1±1.8(8.2, 9.9)	10.7±1.6(9.9, 11.4)
Post 10 min	9.2±1.7 (8.3, 10.0)	10.7±1.7(9.8, 11.5)
R-CPT at 5Hz (0-24 m.A)		
Baseline	12.6±3.5(11.0-14.0)	12.6±2.4 (11.4, 14.0)
Post 1 min	11.1±3.1(9.6, 13.0)	12.9±2.3 (11.8, 14.0)
Post 10 min	11.4±3.1 (9.9,12.8)	13.1±2.2 (12, 14.1)

Abbreviations: DRF =Distal Radius Fracture; Baseline=before cold water immersion; Post 0 min =immediately after period of immersion; Post 1min =1 min after period of immersion; Post 10min=10 min after period of immersion; R-CPT =Ranged Current Perception Threshold Test at 2000Hz for Aβ fibers and at 5Hz for C fibers.
*All values are Mean±standard deviation (95% confidence interval)

between baseline value and immediately (0 min) after POI (p=.00) as well as between baseline and 1 min after POI (p=.003) showed a significant difference. Post hoc comparisons between baseline and 10 min after POI (p=.94) as well as between 0 min and 1 min after POI (p=.06) were not significantly different. Please refer Table 3. Please refer Figures 2 and 3 as an example to show changes observed in the skin blood flow of a patient aged 65 years.

In the DRF hand, the skin temperature was reduced in the index finger from baseline level to immediately after POI (0 min) (p=.00) and 10min later (p=.001). A similar trend was noted in little finger from baseline to both immediately following (0 min) (p=.00) and 10min (p=.002) after POI. Post hoc comparisons (for index and little fingers) between baseline and immediately after POI (0 min) (index p=.002; little p=.01), and between (0 min) immediately after and 10 min after the POI (p=.00; p=004), as well as between baseline and 10 min after POI (p=.002; p=.00) showed significant difference in both index and little fingers. Please refer Table 3.

In the DRF hand, the sensoryperception threshold at 5 Hz remained unaltered by Immersion in cold water evaluation in both injured and uninjured hands (p=.44). Sensory perception threshold

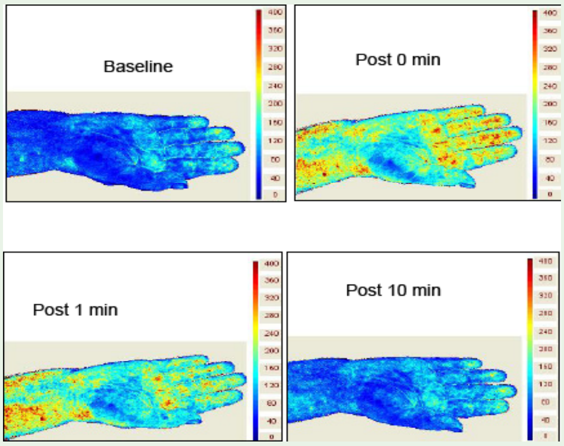

Figure 2: Skin blood flow responses observed in the injured hand (DRF) shown on TiVi camera: Baseline- before cold water immersion; Post 0 min =immediately after period of immersion; Post1min =1 min after period of immersion; Post 10min=10 min after period of immersion.
* Basal skin blood flow appears blue and as it increases the color changes to green, yellow and red as shown on the scale (0-400).

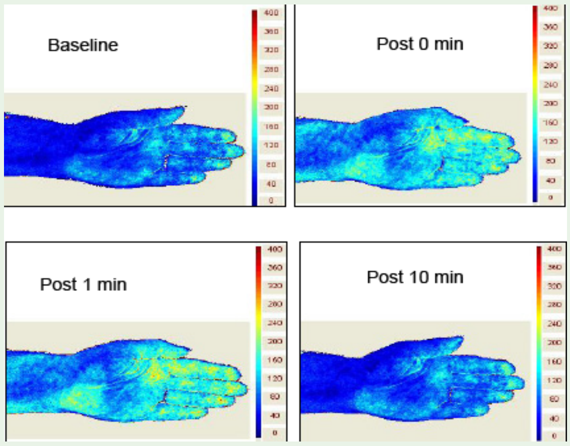

Figure 3: Skin blood flow responses observed in the uninjured hand shown on TiVi camera: Baseline- before cold water immersion; Post 0 min =immediately after period of immersion; Post1min =1 min after period of immersion; Post 10min=10 min after period of immersion
*Basal skin blood flow appears blue and as it increases the color changes to green, yellow and red as shown on the scale (0-400).

at 2000 Hz changed only on the DRF side and showed an increased response from baseline to both immediately after POI (1 min) (p=.006) as well as 10 min after POI (p=.005). Post hoc comparisons between values immediately after POI (1 min) and 10 min after POI were not significantly different (p=1). Please refer Table 3.

Except for the changes in sensory perception threshold at 2000Hz on the DRF side (p=.001), no other significant differences were observed between the injured and uninjured hands on all measures [i.e. skin blood flow (p=.56); skin temperature of index and little fingers (p=.18; p=.97); and sensory perception thresholds at 5Hz (p=.84)]. Nor was an interaction found between hand and time (p=.28).

Discussion

The responses observed in this study are consistent with 'hunting reaction' or the 'Cold Induced Vasodilatation' Phenomenon (CIVD) that has been postulated to explain cold exposure responses. This study found no differences in skin perfusion and rewarming patterns between the previously fractured hand and the unaffected hand of patients presenting at sixth week following a closed reduction. Since patients with vascular injuries were not included in the study, this finding suggests that in the absence of such injury vascular function is relatively "normal." Similarly no difference was observed in C fiber activity after Immersion in cold water evaluation (which carries temperature, pain sensation and sympathetic signals) between the injured and uninjured hands, indicating that these pain fibers were operating at similar detection levels after brief exposure to cold. In contrast Aβ fibers (which carry touch and pressure sensation) responded by an increase in threshold only on the affected side. However, the Aβ thresholds were within the normal range (R-CPT normal level, 6-13); indicating that the fractured hand was less sensitive (hyposensitive) following the cold exposure.

The demonstrated changes in skin blood flow immediately after cold water immersion in this study are consistent with changes in limb blood flow reported by Levy et al., [49]. These authors noted an increase in skin blood flow measured by plethysmography after hand immersion in cold water at 4°C. Even though the cold water temperatures and the methodology used in their study were different than the current protocol, the observed vasodilation in the present study is consistent with that reported by Levy et al. and the previously described "hunting reaction" phenomenon [50]. The term hunting reaction [50] is described as the alternating periods of vasodilation and vasoconstriction during cold exposure until a steady state is reached. Maintained vasodilation without cycling has also been observed with cooling human forearms at 1°C for 15 min [51]. This reaction has implications for assessment and treatment since the clinical rationale for doing each must be consistent with the underlying physiological mechanisms. When the Immersion in cold water evaluation is used to assess abnormal physiological responses to cold, there can be a variety of indicators of this, including abnormal pain in response to cold exposure (detected by numeric pain rating and test completion), failure to achieve expected vasodilation and vasoconstriction during the test, or inability to restabilize blood flow and temperature following exposure. Similarly, the same indicators could negate the therapeutic value of cold if used as a therapeutic agent.

The extremities mitigate the detrimental effects of local cold extremes. In healthy subjects, about 5 to 10 min after the initiation of cold exposure of the hand in a 15°C or cooler environment, the blood vessels suddenly vasodilate to increase peripheral blood flow and maintain fingertip temperatures [38,50,52-54]. Others have reported that this response is stronger when cooling occurs in water in comparison to air [55]. This cold induced vasodilation is followed by a new phase of vasoconstriction to reduce blood flow to the peripheries in favor of a central pooling of blood in the torso and deep body core [56]. This process repeats itself and is called 'the hunting reaction' [50] or Cold Induced Vasodilation (CIVD) reaction [52]. Daanen et al., [52] found that this hunting reaction was present in 210 out of 226 investigated healthy male subjects (93%) who immersed their fingers in ice water. This was also observed in the injured and uninjured fingers/hands of patients with reflex sympathetic dystrophy, [57] as well as patients with median and ulnar nerve lesions [53] after an Isolated cold stress test. This phenomenon is principally attributed to the opening of arterio-venous anastomoses [13] but the exact mechanism is still subject to debate [56].

The changes observed in skin temperature immediately after the cold water immersion in both index and little fingers is consistent with changes reported by Traynor et al., [23] and Smits et al., [21] in the healthy controls and patients with hand fractures [21]. These authors showed that normal active rewarming of the fingers is measurable within 50 to 80 sec after removing the hand from cold water (12°C) and lasts up to 5 or 10 min [23]. Thus, after an extensive cooling of the extremities, the thermoregulatory system increases the blood flow to the extremity to counteract the decrease in hand temperature and prevent pain and/or frostbite [31].

The current study provides new information about the response patterns in different nerve fibers to cold exposure. No alteration in small C fiber functionality was demonstrated. A small increase in threshold for the larger Aβ fibers was demonstrated in the injured hand. Since this is the first report of this finding, we cannot verify it from other studies on cold exposure. However, there are previous reports on sensory nerve conduction velocity observed after cryotherapy in healthy subjects using ice packs [56,57] and cold water immersion [58]. These studies have demonstrated that peripheral sensory nerve conduction velocity is slowed by cold application [58,59]. Because nerve conduction studies can measure sensory nerve conduction velocity of large diameter nerve fibers, [60] the increase in Aβ threshold (threshold increase corresponds to hyposensitivity or decreased sensation) observed after cold water immersion in this study is consistent with the decrease in sensory nerve conduction velocity observed by Esperanza et al.,[58]. Previous studies have demonstrated that topical cold treatment decreases the skin temperature and in underlying tissues to a depth of 2 to 4 cm, [58,61-63] decreasing the conduction velocity of pain nerve signals [57,58,63]. This result in a local anesthetic effect called cold-induced neuropraxia. We did not demonstrate evidence of this in our 5 Hz thresholds which target the small unmyelinated pain fibers (C fibers). The fact that injured and uninjured hands showed no variation in C fiber thresholds with the brief cold exposure, suggests that the cold water exposure resulted in minimal thermal, nociceptive or sympathetic physiological responses. Nerve fiber sensitivity is thus presumed to vary according to the diameter and myelination of the nerve [64]. The large diameter, myelinated nerve fibers are thought to be most responsive to cold exposure, whereas the small unmyelinated fibers are thought to be least affected by the cold [64].

The current study objectively examined thermoregulatory, sensory and vascular function after DRF by evaluating skin blood flow, skin temperature, Aβ and C fiber responses before and after a cold provocation test (Immersion in Cold water Evaluation). Normal thermo-physiological responses such as Cold Induced Vasodilation (CIVD) reaction, [19,39] and digital rewarming patterns, [31,50,52] were noted in both the injured and uninjured hands. These findings suggest that a brief exposure to cold water has a potential to induce some therapeutic effects in patients with uncomplicated DRF and needs further investigation.

Glady et al., [27] demonstrated that ice pack reduced pain, swelling and improved the range of motion in patients with DRF after cast removal. Whereas, other reports have stated that cold water immersion is preferable to ice packs [58,63,65]. Cold water immersion is thought to cause the least skin temperature reduction, possibly due to the fact that a greater area receives the treatment, leading to a faster activation of the thermoregulatory responses that protect the body from abrupt temperature changes [66] and consequently, the skin temperature is quickly stabilized and does not adequately reflect the effects of cooling on subcutaneous tissues [67-70]. The temperature reductions of approximately 10°C in both index and little fingers along with the changes in skin blood flow, perception thresholds in Aβ fibers and the possible mechanisms behind these changes led us to a conclusion that cold water immersion for 5 min. has a potential to reduce pain; and can act as a counter-irritant via pain gate mechanism through the activation of large diameter Aβ fibers which needs a further study [64,71,72]. The increase in Aβ threshold only on the DRF side after cold water immersion could be attributed to the ongoing healing process which was possibly absent in the normal tissue. Cold application helps to reduce swelling in the DRF patients after cast removal, as demonstrated by Glady et al., [27]. However, when cold is used to reduce swelling, then the position of the extremity must also be considered. Some have used contrast baths, alternating immersion in cold and hot water. A systematic review and effectiveness of contrast baths was inconclusive [71]. It might be useful to examine different approaches to cold application using the approach conducted in this study to determine potential differences in physiological effects across methods of administering thermal agents.

Limitations and Research Recommendations

There are a number of limitations in the current study that may have affected the study findings and generalizability. Results are mostly applicable to female patients and those who had a fall on an outstretched hand. Thus, these findings may not apply where complications, surgery or pre-existing co morbidities are present. Only one therapist pro-vided the testing and assessments. However minimal bias was expected with respect to the evaluation of all three measures, because sensory perception threshold was determined by the patient while the Tissue viability imaging and skin temperature were not controlled by either the patient or the therapist.

Simultaneous measurements on all measures was not possible hence, the responses at regular intervals up to 10 min after cold water immersion were not reported. Since the ring finger (test site) is innervated by median and ulnar nerves, differential effects in these nerves were not directly explored. Therefore, future research on Immersion in cold water evaluation should focus on single nerve territory.

Cold induced vasodilation is thought to vary according to age, gender, ethnicity and acclimatization to cold weather etc [22,56] thus; future research can observe people based on these factors. A normal response to objective cold test does not prevent subjective symptoms of cold intolerance (on Cold Intolerance Symptom Severity scale or

CISS) [21,53] hence it is important to include self-report measures of cold intolerance such as CISS along with physiological measures such as TiVi after cold water immersion test.

Knowledge of the short term and long term physiologic effects informs our understanding about the safety and therapeutic benefit of cold water immersion. Future studies should include a large cohort and undertake trajectory analysis to determine complications following DRF. This may help clinicians and therapists in the early detection and secondary prevention. We also suggest that future studies specifically target DRF patients with neurovascular dysfunction and cold intolerance to determine to what extent they behave differently than the uncomplicated cases used in this study. Future studies are also needed to explore the effects in patients with different hand conditions and observe responses on outcomes such as pain, swelling, joint range of motion and days to return to work.

Conclusion

We conclude that brief cold water exposure results in a higher skin blood flow and lower skin temperature to the digital extremities for around 10 min in the injured and uninjured hands of people recovering from DRF. No changes were found in sensory perception thresholds of C fibers (5 Hz) or Aβ fibers (2000 Hz) of uninjured hands. A small increase in sensory perception threshold of the Aβ fibers was measurable on the injured hand. The findings are consistent with physiological under pinning's of cold exposure if used as therapeutic agent or a test exposure.

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References

1. Handoll HHG, Madhok R, Howe TE. Rehabilitation for distal radial fractures in adults. 2006; 19: CD003324.
2. Sahlin Y. Occurrence of fractures in a defined population: a 1-year study. Injury. 1990; 21: 158-160.
3. Singer BR, Mc Lauchlan GJ, Robinson CM, Christie J. Epidemiology of fractures in 15,000 adults: the influence of age and gender. J Bone Joint Surg – British. 1998; 80: 243-248.
4. Collins DC. Management and rehabilitation of distal radius fractures. Orthop Clin North Am. 1993; 24: 365-378.
5. Court-Brown CM, Caesar B. Epidemiology of adult fractures: A review. Injury. 2006; 37: 691-697.
6. American Academy of Orthopaedic Surgeons. The treatment of distal radius fractures: guideline and evidence report. Adopted by the American Academy of Orthopaedic Surgeons Board of Directors. 2009.
7. Byl NN, Kohlhase W, Engel G. Functional limitation immediately after cast immobilization and closed reduction of distal radius fracture: preliminary report. J Hand Ther. 1999; 12: 201-211.
8. Handoll HHG, Madhok R. Conservative interventions for treating distal radial fractures in adults (Cochrane Review).Cochrane Database of Systematic Reviews. 2003; 2.
9. MacDiarmid JC, Roth JH, Richards RS. Pain and disability reported in the year following a distal radius fracture: a cohort study. BMC Musculoskelet Disord. 2003; 4: 24.
10. McKay SD, Mac Dermid JC, Roth JH. Assessment of complications of distal radius fractures and development of a complication checklist. J Hand Surg Am. 2001; 26: 916-922.
11. Kay S, McMahon M, Stiller K. An advice and exercise program has some benefits over natural recovery after distal radius fracture: a randomised trial. Aust J Physiother. 2008; 54: 253-259.
12. Collins ED, Novak CB, Mackinnon SE. Long-term follow- up evaluation of cold sensitivity following nerve injury. J Hand Surg. 1996; 21: 1078-1085.
13. Fox RH, Wyatt HT. Cold-induced vasodilatation in various areas of the body surface of man. J Physiol. 1962; 162: 289-297.
14. Irwin MS, Gilbert SE, Terenghi G, Smith RW, Green CJ. Cold intolerance following peripheral nerve injury. Natural history and factors predicting severity of symptoms. J Hand Surg Br. 1997; 22: 308-316.
15. Ruijs AC, Jaquet JB, van Riel WG, Daanen HA, Hovius SE. Cold intolerance following median and ulnar nerve injuries: prognosis and predictors. J Hand Surg Eur. 2007; 32: 434-439.
16. Campbell DA, Kay SP. What is cold intolerance? J Hand Surg. 1998; 23: 3-5.
17. Lithell M, Backman C, Nystrom A. Pattern recognition in post-traumatic cold intolerance. J Hand Surg. 1997; 22: 783-787.
18. Nancarrow JD, Rai SA, Sterne GD, Thomas AK. The natural history of cold intolerance of the hand. Injury. 1996; 27: 607-611.
19. Nijhuis TH, Smits ES, Jaquet JB, Van Oosterom FJ, Selles RW, Hovius SE. Prevalence and severity of cold intolerance in patients after hand fracture. J Hand Surg Eur. 2010; 35: 306-311.
20. MacDiarmid JC. Measurement of health outcomes following tendon and nerve repair. J Hand Ther. 2005; 18: 297-312.
21. Smits ES, Nijhuis TH, Huygen FJ, Selles RW, Hovius SE, Niehof SP. Rewarming patterns in hand fracture patients with and without cold intolerance. J Hand Surg Am. 2011; 36: 670-676.
22. Stephen SC, Daanen HAM. Dynamic adaptation of the peripheral circulation to cold exposure. Microcirculation. 2012; 19: 65-77.
23. Traynor R, MacDermid JC. Immersion in Cold-Water Evaluation (ICE) and self-reported cold intolerance are reliable but unrelated measures. Hand (NY). 2008; 3: 212-219.
24. Bear MF, Connors BW, Paradiso MA. The somatic sensory system. In Neuroscience: Exploring the Brain, 3rd ed. Philadelphia: Lippincott Williams & Wilkins pp. 2007; 387-421.
25. Ruch DS, Vallee J, Li Z Smith BP, Holden M, Koman LA. The acute effect of peripheral nerve transection on digital thermoregulatory function. J Hand Surg Am. 2003; 28: 481-488.
26. Michlovitz SL, LaStayo PC, Alzner S. Distal radius fractures: therapy practice patterns. J Hand Ther. 2001; 14: 249-257.
27. Gladys LYC, Jolly WH, Wan, Sing Kai Lo. Ice and pulsed magnetic electromagnetic field to reduce pain and swelling after distal radius fractures. J Rehabil Med. 2005; 37: 372-377.
28. Pollock FE Jr, Koman LA, Smith BP, Poehling GG. Patterns of microvascular response associated with reflex sympathetic dystrophy of the hand and wrist. J Hand Surg Am. 1993; 18: 847-852.
29. Atkins RM. Post-traumatic reflex sympathetic dystrophy. In: Ficat CCJ, eds. Balliere's Clinical Orthopaedics - Reflex Sympathetic Dystrophy. London: Bailliere Tindall. 1996; 1: 223-240.

30. Koman LA, Slone SA, Smith BP, Ruch DS, Poehling GG. Significance of cold intolerance in upper extremity disorders. J South Orthop Assoc. 1998; 7: 192-197.

31. Koman LA, Smith BP, Smith TL. Stress testing in the evaluation of upper extremity perfusion. Hand Clin. 1993; 9: 59-83.

32. Rousitt M, Maggi F, Isnard S, Hellmann M, Bakken B, Cracowski JL. Reproducibility of local cooling test to assess micorvascular function in human skin. Microvasc res. 2010; 79: 34-39.

33. Camero M, Verdugo RJ, Ochoa JL. Vasomotor innervations of the skin of the hand: a contribution to the study of human anatomy. J Anat. 1993; 182: 361-368.

34. Merskey H, Bogduk N. Classification of Chronic Pain. 2nd ed. International Association for the Study of Pain, Seattle. 1994.

35. Neurotron, Incorporated. Technical operating manual. Available at: CPTC_manual.pdf. 2012.

36. Sunderland S. Nerves and nerve injuries, 2nd ed. New York: Churchill-Livingstone. 1978.

37. http://www.neurotron.com/diagnostic_applications.html

38. Charkoudian N. Mechanisms and modifiers of reflex induced cutaneous vasodilation and vasoconstriction in humans. J Appl Physiol. 2010; 109: 1221-1228.

39. Pollock FE, Koman LA, Smith BP, Holden M, Russell GB, Poehling GG. Measurement of hand microvascular blood flow with isolated cold stress testing and laser Doppler fluxmetry. J Hand Surg. 1993; 18: 143-150.

40. Cohen J. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NJ: Lawrence Earlbaum Associates. 1988.

41. Nilsson GE, Zhai H, Chan HP, Farahmand S, Maibach HI. Cutaneous bioengineering instrumentation standardization: the Tissue Viability Imager. Skin Res Technol. 2009; 15: 6-13.

42. McNamara PM, O'Doherty J, O'Connell ML, Fitzgerald BW, Anderson CD, Nilsson GE, et al. Tissue viability (TiVi) imaging: temporal effects of local occlusion studies in the volar forearm. J Biophotonics. 2010; 3: 66-74.

43. O'Doherty J, Henricson J, Anderson C, Leahy MJ, Nilsson GE, Sjöberg. Subepidermal imaging using polarized light spectroscopy for assessment of skin microcirculation. Skin Res Technol. 2007; 13: 472-484.

44. Henricson J, Nilsson A, Tesselaar E, Nilsson G, Sjoberg F. Tissue viability imaging: microvascular response to vasoactive drugs induced by iontophoresis. Microvasc Res. 2009; 78: 199-205.

45. O'Doherty J, McNamara P, Clancy NT, Enfield JG, Leahy MJ. Comparison of instruments for investigation of microcirculatory blood flow and red blood cell concentration. J Biomed Optics. 2009; 14: 034025.

46. Costantini M, Tunks K, Wyatt C, Zettel H, MacDermid JC. Age and upper limb tension testing affects current perception thresholds. J Hand Ther. 2006; 19: 307-316.

47. Uddin Z, MacDermid JC, Galea V, Gross AR, Pierrynowski M. The Current Perception Threshold Test Differentiates Categories of Mechanical Neck Disorder. J Orthop Sports Phys Ther. 2014; 10.

48. Nishimura A, Ogura T, Hase H, Makinodan A, Hojo T, Katsumi Y, et al. Objective evaluation of sensory function in patients with carpal tunnel syndrome using the current perception threshold. J Orthop Sci. 2003; 8: 625-628.

49. Levy B, Ghaem A, Verpillat JM, Martineaud JP. Effects of ambient and local cutaneous temperatures on hand blood flow. Int J Biometeorology. 1977; 21: 341-347.

50. Lewis T. Observation upon the reactions of vessels of the human skin to cold. Heart. 1930; 15: 177-208.

51. Clarke RS, Hellon RF, Lind AR. Vascular reactions of the human forearm to cold. Clin Sci (Lond). 1958; 17: 165-179.

52. Daanen HAM. Cold injury risk of marines. Report TM-A050. TNO Human Factors, Soesterberg. 2001.

53. Ruijs AC, Niehof SP, Hovius SE, Selles RW. Cold-induced vasodilatation following traumatic median or ulnar nerve injury. J Hand Surg Am. 2011; 36: 986-993.

54. Sendowski I, Savourey G, Besnard Y, Bittel J. Cold induced vasodilatation and cardiovascular response in humans during cold water immersion of various upper limb areas. Eur J Appl Physiol. 1997; 75: 471-477.

55. Van der Struijs NR, Van Es EM, Raymann RJ, Daanen HAM. Finger and toe temperatures on exposure to cold water and cold air. Aviat Space Environ Med. 2008; 79: 941-946.

56. Daanen HAM. Finger cold-induced vasodilation: a review. Eur J Appl Physiol. 2003; 89: 411-426.

57. Algafly AA, George KP. The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance. Br J Sports Med. 2007; 41: 365-369.

58. Esperanza H, Sandoval MC, Camargo DM, Salvini TF. Motor and sensory nerve conduction are affected differently by ice pack, ice massage, and cold water immersion. Phys Ther. 2010; 90: 581-591.

59. Lee JM, Margaret PW, Mason S M. Effects of ice on nerve conduction velocity. Physiotherapy. 1978; 64: 2-6.

60. Nishimura A, Ogura T, Hase H, Makinodan A, Hojo T, Katsumi Y, et al. A correlative electrophysiologic study of nerve fiber involvement in carpal tunnel syndrome using current perception thresholds. Clin Neurophysiol. 2004; 115: 1921-1924.

61. Dyckstra JH, Hill HM, Miller MG, Cheatham CC, Michael TJ, Baker RJ. Comparisons of cubed ice, crushed ice, and wetted ice on intramuscular and surface temperature changes. J Athl Train. 2009; 44: 136-141.

62. Halar EM, DeLisa JA, Brozovich FV. Nerve conduction velocity: relationship of skin, subcutaneous and intramuscular temperatures. Arch Phys Med Rehabil. 1980 61: 199-203.

63. Nadler SF, Feinberg JH, Reisman S, Stitik TP, DePrince ML, Hengehold D, et al. Effect of topical heat on electromyographic power density spectrum in subjects with myofascial pain and normal controls: a pilot study. Am J Phys Med Rehabil. 2001; 80: 809-815.

64. Douglas WW, Malcolm JL. The effect of localized cooling on cat nerves. J Physiol. 1955; 130: 53-57.

65. Wilcock IM, Cronin JB, Hing WA. Physiological responses to water immersion: A method for Sport Recovery? Sports Med. 2006; 36: 747-765.

66. Tikuisis P, Gonzalez RR, Pandolf KB. Thermoregulatory model for immersion of humans in cold water. J Appl Physiol. 1988; 64: 719-727.

67. Bugaj R. The cooling, analgesic, and rewarming effects of ice massage on localized skin. Phys Ther. 1975; 55: 11-19.

68. Casey DP, Curry TB, Joyner MJ. Measuring muscle blood flow: a key link between systemic and regional metabolism. Curr Opin Clin Nutr Metab Care. 2008; 11: 580-586.

69. Chesterton LS, Foster NE, Ross L. Skin temperature response to cryotherapy. Arch Phys Med Rehabil. 2002; 83: 543-549.

70. Jutte LS, Merrick MA, Ingersoll CD, Edwards JE. The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming. Arch Phys Med Rehabil. 2001; 82: 845-850.

71. Breger SDE, Lazaro R, MacDermid JC. A systematic review of the effectiveness of contrast baths. J Hand Ther. 2009; 22: 57-69.

72. Hocutt JE, Jaffe R, Rylander CR, Beebe JK Cryotherapy in ankle sprains. Am J Sports Med. 1982; 10: 316-319.