ORIGINAL ARTICLE

Changes in Lower-Leg Blood Flow During Warm-, Cold-, and Contrast-Water Therapy

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ABSTRACT. Fiscus KA, Kaminski TW, Powers ME. Changes in lower-leg blood flow during warm-, cold-, and contrast-water therapy. Arch Phys Med Rehabil 2005;86: 1404-10.

Objective: To examine arterial blood flow in the lower leg during warm-, cold-, and contrast-water therapy.

Design: A crossover trial with repeated measurements on the dependent variable.

Setting: Hydrotherapy area of a climate-controlled sports medicine clinic.

Participants: A volunteer sample of 24 healthy men.

Intervention: Four randomly assigned treatments were performed on each subject on consecutive days.

Main Outcome Measure: Arterial blood flow (mL per 100mL/min) from baseline measurements were recorded in a 3-minute to 1-minute on-off ratio for 20 minutes by using strain gauge plethysmography.

Results: Contrast therapy produced fluctuations in blood flow throughout the 20-minute treatment. Warm-water therapy (40°C) resulted in significant ($P<.001$) changes in blood flow compared with the control and contrast conditions. Cold-water therapy (13°C) did not produce significantly decreased blood flow as compared with the control condition.

Conclusions: We suggest that further studies involving contrast therapy to the lower leg in injured populations be carried out to determine whether our initial findings are clinically relevant.

Key Words: Cryotherapy; Hydrotherapy; Plethysmography; Rehabilitation.

VARIOUS MODALITIES ARE OFTEN used to treat the symptoms associated with local inflammation, which is a response to tissue trauma. Included among these treatments are hot and cold therapies, which typically involve the use of moist heat packs, warm and cold hydrotherapy, and ice treatments. Previous research has suggested that the application of these modalities will produce changes in pain perception,[1] metabolism,[2,3] temperature,[4-7] edema formation,[8] and blood flow.[9-16] A popular technique used by athletic trainers and other clinicians involves the alternating of hot- and cold-water immersions, more commonly referred to as *contrast therapy*. The ratios of heat to cold vary, but most recommend ratios of 3:1 or 4:1 minutes.[17-19] Contrast baths are sometimes used when shifting the treatment modality from cold to heat and to facilitate a mild increase in tissue temperature.[17] The mild temperature increase is purported to provide an effective means for increasing blood flow to the injured area without causing accumulation of additional edema. At this time, however, very little information exists to substantiate this claim.[4,5]

Additionally, it has been theorized that contrast therapy causes a cycle of local vasoconstriction and vasodilation, creating a type of "pumping" action that would enhance *venous* and *lymphatic* removal of edema.[17] Specifically, the current thought is that the edema is removed because the constriction increases the intraluminal pressure in the vessel, causing the fluid to move with the valves in veins, thus preventing backflow of the fluid.[20] The benefit of this would be to minimize the influence of edema accumulation during the normal healing process. However, this vascular pumping theory is not well supported because the majority of the research involving vascular changes has been limited to isolated hot or cold treatments and not contrast therapies.[9-16] Furthermore, lymphatic drainage is thought to occur as a result of active exercise or the muscle pump.[20] Denegar states, "the brief exposure to cold and the fact that superficial heating has minimal effect on deep blood flow suggest that there is little vascular response to contrast therapy."[19(p118)] Furthermore, smooth muscle-induced intrinsic contraction of the vessel wall is only a small contributor to lymphatic flow. More importantly, the lymph capillaries do not have muscular walls and therefore do not contribute in any meaningful way to a "pumping" (dilation and constriction) mechanism.[20] The lack of studies involving the investigation of vascular changes during contrast therapy using more sophisticated and contemporary technology leaves room for further research in this area.

The purpose of our investigation was to examine the change in arterial blood flow in the lower leg during warm-, cold-, and contrast-water therapy using strain gauge plethysmography. We hypothesized that (1) 20 minutes of contrast therapy would produce significantly increased lower-leg blood flow as compared with both the control and cold-water therapy, (2) 20 minutes of contrast therapy would produce decreased lower-leg blood flow as compared with warm-water therapy, (3) 20 minutes of warm-water therapy would produce significantly increased lower-leg blood flow as compared with the control, and (4) 20 minutes of cold-water therapy would produce significantly decreased lower-leg blood flow as compared with the control.

METHODS

Design

We used a repeated-measures crossover trial design for this investigation. The independent variables included 4 levels of treatment (20-min control; 20-min warm [40°C] water therapy; 20-min cold [13°C] water therapy; 20-min contrast-water therapy) and time interval (65 recorded intervals). The order of

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Table 1: Subject Demographics

Subject No.	Age (y)	Height (cm)	Mass (kg)	Calf Circumference (cm)	Gauge Size
1	30	170.2	74.8	37.0	34
2	24	185.4	97.5	43.0	40
3	23	182.9	79.4	40.0	38
4	23	180.3	63.5	33.0	30
5	25	180.3	74.8	39.5	38
6	21	180.3	71.7	38.0	36
7	23	167.6	74.8	40.0	38
8	22	180.3	70.3	37.5	36
9	21	162.6	68.0	35.0	32
10	25	182.9	92.1	41.0	38
11	25	177.8	88.5	42.0	40
12	24	177.8	90.7	38.5	36
13	27	180.3	79.4	38.5	36
14	19	182.9	62.1	32.5	30
15	24	172.7	74.8	35.5	34
16	23	177.8	81.7	38.0	36
17	21	172.7	74.8	35.5	34
18	20	172.7	99.8	45.0	42
19	21	188.0	72.6	38.0	36
20	21	177.8	79.4	39.0	36
21	19	175.3	57.6	32.5	30
22	23	175.3	63.5	32.5	30
23	25	177.8	89.8	41.0	38
24	24	167.6	71.7	37.5	36

treatment was randomly assigned by using a counterbalanced scheme.

Participants

Twenty-four men (age, 23.0±2.5y; height, 177.1±6.1cm; mass, 77.2±3.4kg) who were free from injury, circulatory problems, cold allergies, and had midcalf circumferences between 24 and 45cm volunteered for this study (table 1). To prevent fluctuations in blood flow caused by exercise, we recruited only sedentary people. We also excluded subjects if they were taking any medications that may affect heart rate and blood flow such as β-adrenergic blocking drugs, digitalis preparations, calcium channel blockers, diuretics, β_2-agonists, or anti-inflammatory drugs. We instructed subjects to refrain from ingesting caffeine 12 hours before their measurement sessions and to maintain normal fluid and caloric intake during the 4 days of their testing, so not to cause fluctuations in their hydration level. Before participating, each volunteer was asked to read a description of the protocol and sign an informed consent agreement, which was approved by the university's institutional review board.

Instrumentation

EC6 strain gauge plethysmograph. An EC6 strain gauge plethysmograph[a] was used to measure blood flow in the lower leg. Electrically calibrated strain gauge plethysmography is a system of measuring limb blood flow.[21] Our system of measurement may also be referred to as *arterial inflow* or *venous occlusion* plethysmography. A 4-wire limb gauge is placed around the middle of the muscle, and cuffs are placed above and below the gauge. With every heart beat, blood is pooled into the area and the circumference of the limb changes. Keep in mind that the venous return is occluded with a pressure that does not interfere with arterial blood flow. Strain gauge plethysmography measures the rate of change (slope) of the circumference of a limb. This slope is interpolated to represent change in limb volume by using the unit mL per 100mL/min. Technically, this represents a change in the volume of the limb segment over a brief period of time rather than the change in blood flow. However, because the change in volume is assumed to be the result of arterial inflow of blood, the convention is to report the change as blood flow.[21]

The parameters of the plethysmograph were set according to the manufacturer guidelines. The reading interval (the period between readings) was set at 15 seconds, and the sample/inflow time (the amount of time between inflation and deflation of the thigh cuff) was set at 5 seconds. These settings allowed the plethysmograph to automatically inflate and deflate the thigh cuff (fig 1) at the specified interval. The air pressure for the thigh cuff was set at 50mmHg. This inflation pressure was sufficient enough to stop venous return from the leg while still allowing arterial inflow.[21] The vein mode was set on the plethysmograph in accordance with the other settings. In this mode, the signal from the strain gauge is directly coupled to the recorder without any filters to distort the signal, which allows the instrument to record continuous changes in blood flow.

The EC6 strain gauge plethysmograph is compatible with the Noninvasive Vascular Program (NIVP3) software[a] that interfaces the laptop computer with the plethysmograph. The NIVP3 software stores patient information and waveforms for arterial inflow measurements. Blood flow was measured by a mercury-in-rubber strain gauge[a] secured around the largest circumferential point of the left calf and connected to the plethysmograph. The strain gauges ranged in size from 22 to 42cm; we used sizes that ranged from 30 to 42cm. Accurate electric calibration requires that the gauge be 1 to 3cm smaller than the circumference of the limb. The limb gauges are a double loop of mercury filled rubber that were placed around the calf and hooked over the end of the gauge. The end was taped to the skin to minimize the space between the gauge and the skin and to prevent small movements of the cable from perturbing the gauge (see fig 1).

Strain gauge plethysmography is considered a reliable and valid method for measuring limb blood flow.[21] We performed a reliability analysis of the EC6 strain gauge plethysmograph and its ability to accurately assess baseline blood flow in a

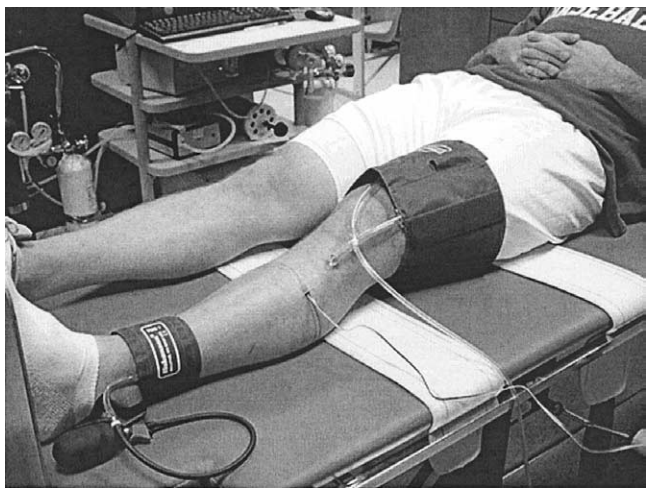

Fig 1. Experimental setup showing the thigh and ankle cuffs of the plethysmograph with the mercury-in-rubber strain gauge secured to the midcalf region.

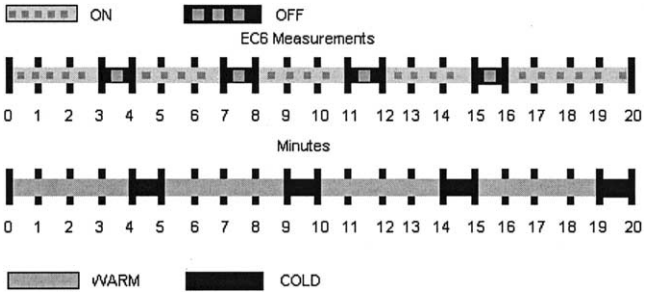

Fig 2. Measurement time scheme for the plethysmograph blood flow readings.

group of 9 subjects on 2 separate occasions. The resultant intraclass correlation coefficient (ICC) model $ICC_{2,1}$ value was .87, with a corresponding standard error of the mean of .06%. These values represent excellent reliability and precision of measurement.

Whirlpool tank. A stainless-steel extremity whirlpool tank[b] was used for all lower-leg immersions involving both cold (13ºC) and warm (40ºC) water. Another extremity whirlpool tub was placed adjacent to this tank and used for the cold-water immersions during the contrast therapy treatment only. The tank was left empty during the control treatment session. A thermometer attached to the tank was used to ensure consistency in the water temperatures.

Procedures

On arrival, we measured the left midcalf circumference with a measuring tape. We then instructed subjects to sit quietly for 20 minutes in the whirlpool chair positioned near the whirlpool tanks. After this 20-minute rest period, we measured blood pressure on the left arm by using a manual sphygmomanometer[c] and recorded this within the NIVP3 software. The inflation cuffs were secured around the left thigh and ankle. An appropriately sized mercury-in-rubber strain gauge was fastened around the midcalf area and secured with athletic tape as we previously described. An instrument check initiated by the NIVP3 software ensured that all input and output devices were reading correctly before we continued. We then balanced the plethysmograph analog output gauge so that the gauge was centered between 0 and 1, thus allowing an appropriate range for the computer to graph the blood flow measurements.

With the subject still seated, we quickly inflated the ankle cuff 10mmHg above the subject's diastolic blood pressure and subsequently recorded baseline blood flow. We then immersed the subject's left leg into the appropriate whirlpool tank to a point just below the knee joint line. The plethysmograph began recording blood flow for 3 minutes. After 3 minutes, we deflated the ankle cuff and suspended the readings on the computer screen for 1 minute. After the 1 minute of rest, the ankle cuff was once again inflated and blood flow measurements resumed. The ankle cuff can only be inflated for 5 minutes at a time because it is too restricting on blood flow to the foot and ankle. We chose an inflation time of 3 minutes because it was comfortable enough for subjects to tolerate and did not interfere with the cold sessions within the contrast treatment. A 4-minute inflation time was also an option, but it was uncomfortable for subjects and it was also the same ratio (4:1) as the contrast treatment and would not have enabled us to record data for any of the cold sessions during the contrast condition. This 3:1 recording scheme was repeated for all measurements during each of the 4 treatment sessions.

The 3:1 minute blood flow-recording scheme did not allow for readings to be recorded during the last minute of the treatment session (at this point, the plethysmograph is turned off). To allow a reading to be taken during the 20th minute, the 3:1 minute scheme was disrupted (fig 2). After the 16th minute, 4 minutes of measurements were taken to obtain a blood flow measurement during the last minute of the treatment session. At the conclusion of the treatment session, the blood flow measurements were discontinued.

Subjects were then asked to return to the laboratory at the same time over the course of the next 3 consecutive days to undergo testing under the other treatment conditions. The procedures described earlier were followed at each of these subsequent treatment sessions. For the control condition, we asked the subjects to sit quietly in the whirlpool chair with their test leg positioned in an empty whirlpool tank.

Statistical Analysis

We used the Statistical Package for the Social Sciences, version 9.0.0,[d] to perform the statistical analyses. The percentage change in local blood flow (rate of change of limb segment circumference) during each 5-second sampling period served as the dependent measure in this investigation. The percentage change in blood flow was defined as the change from the baseline blood flow measurement recorded at the beginning of each 20-minute treatment session. The percentage change was measured every 15 seconds, comparing baseline with each of the measurements in the 3-minute on-time phase. Statistical significance was assessed by using a repeated-measure analysis of variance (ANOVA) with 2 within-subject factors (treatment, time). If significant differences were detected between the 4 treatment levels or multiple time intervals, Tukey honestly significant difference post hoc analyses were conducted. An a priori level of significance of P less than .05 was used for all comparisons.

RESULTS

The ANOVA revealed a significant treatment main effect ($F_{3,30}=38.8$, $P<.001$) with change in blood flow differences greater than .66mL per 100mL/min considered noteworthy, as determined by the Tukey post hoc analysis (fig 3). Specifically, a significant increase in blood flow was observed during the

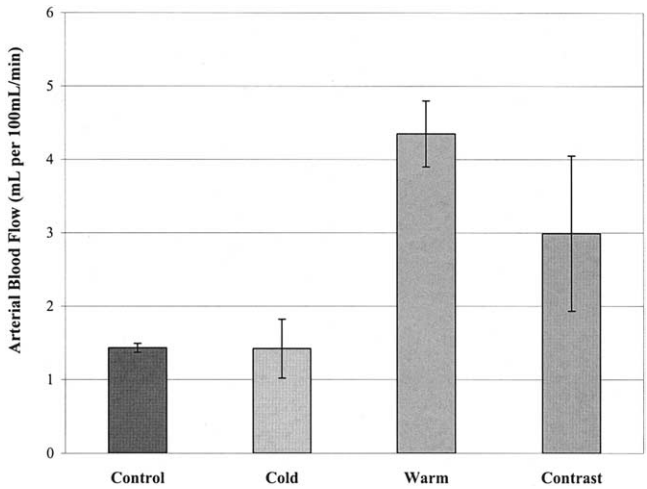

Fig 3. Average change in blood flow from baseline across all 4 treatment conditions (treatment main effect).

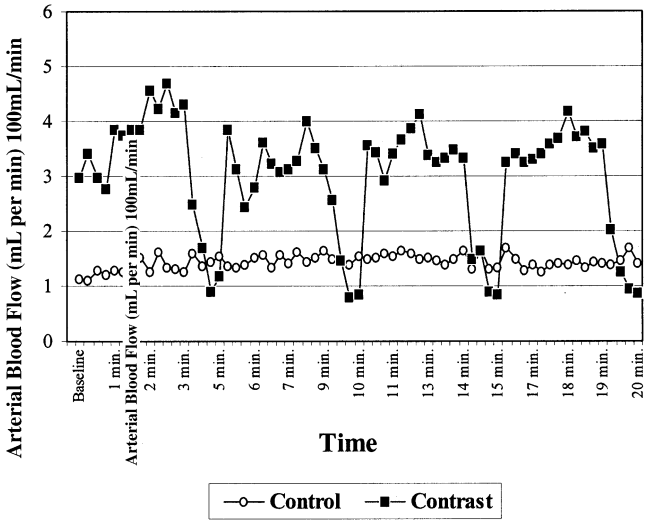

Fig 4. Change in blood flow between the control and contrast conditions. Note that baseline indicates the point when blood flow measurements began.

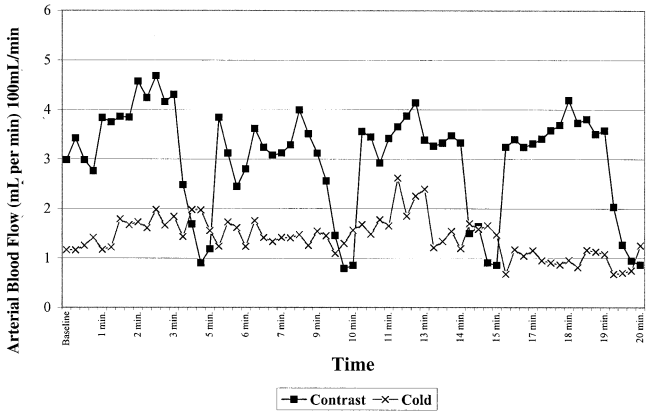

Fig 5. Change in blood flow between the contrast and cold conditions. Note that baseline indicates the point when blood flow measurements began.

warm-water immersion (4.35±0.45mL per 100mL/min) and contrast (2.99±1.66mL per 100mL/min) conditions as compared with the cold-water immersion (1.41±0.40mL per 100mL/min) and control (1.43±0.06mL per 100mL/min) conditions. There were no differences between the cold-water immersion and control conditions. Furthermore, there was a significant condition by time interaction ($F_{192,1920}=3.08$, $P<.001$). For this part of the analysis, the Tukey post hoc testing determined that differences of 1.13mL per 100mL/min or more change in blood flow were considered significant. Because of the complex nature of all comparisons involved in this interaction, only the a priori planned comparisons were examined.

Contrast Therapy

A significant increase in blood flow from baseline was observed during each warm-water phase of the contrast therapy; however, these changes were not observed during the cold-water phases (fig 4). When the cold-water phases of the contrast therapy were compared with the corresponding time points of the cold-water immersion, no differences were observed, although transient fluctuations did occur (fig 5). When the warm-water phases from both the warm and contrast therapies were compared, a significantly greater change in blood flow in the warm therapy was observed at the end of the third and beginning of the fourth measurement cycles (fig 6).

Warm-Water Immersion

A significant change in blood flow from baseline was observed across the entire warm-water immersion. The greatest increase in blood flow occurred during the initial 4.5 minutes and the final 10 minutes of the treatment session (fig 7). As expected, the warm-water condition resulted in a significant increase in blood flow as compared with both the control and cold-water conditions throughout the entire 20-minute treatment session.

Cold-Water Immersion

The change in blood flow from baseline during cold-water immersion was nearly equivalent to the change in blood flow during the control condition at all time points. Other than some transient outliers during the cold condition, no significant changes in blood flow were observed across the entire treatment time (fig 8).

DISCUSSION

The results of this study suggest that contrast therapy produced fluctuations in blood flow throughout the 20-minute treatment. Several studies[9-13] have been conducted measuring blood flow during hot and cold whirlpool therapy, whereas none have been performed measuring blood flow during contrast therapy. Furthermore, several other studies[2,3,14-16] have been conducted examining the effects of other cold therapies on localized blood flow. These studies examined blood flow during cold gel pack or ice bag treatments by using various application durations. All of the studies consistently revealed decreased blood flow at 20 minutes after application. Interestingly, the study by Karunakara et al[14] revealed that blood flow was reduced during a prolonged (60-min) intermittent cold application. Three of these studies[14-16] used an impedance plethysmograph to measure blood flow, whereas 2 others[2,3] used triple-phase technetium bone scans to measure blood

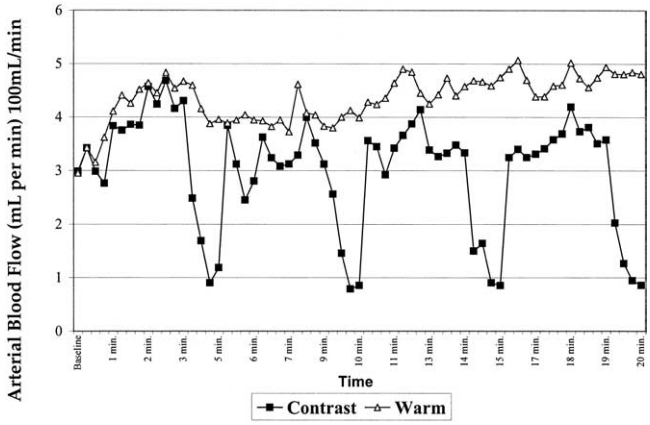

Fig 6. Change in blood flow between the contrast and warm conditions. Note that baseline indicates the point when blood flow measurements began.

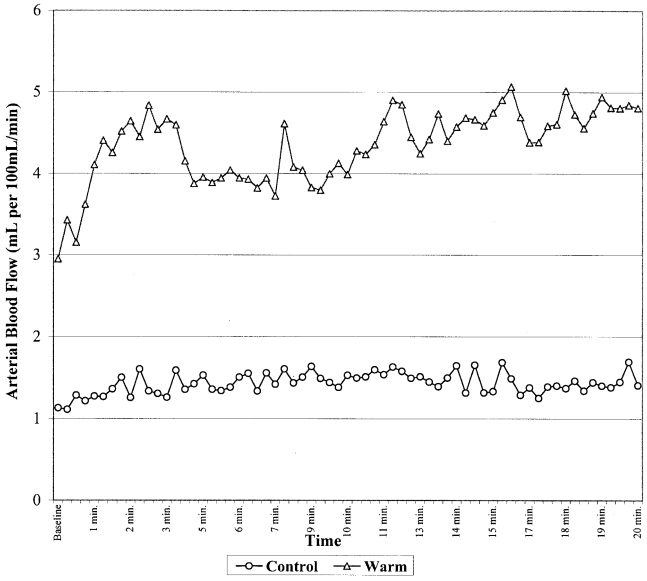

Fig 7. Change in blood flow between the control and warm conditions. Note that baseline indicates the point when blood flow measurements began.

flow. It should also be noted that several of the studies[9-13] were conducted more than 40 years ago.

Strain Gauge Plethysmography

The need for more contemporary research involving contrast therapy as a treatment modality is vital. In 1975, Hokanson et al[21] developed an electrically calibrated plethysmograph to directly measure limb blood flow. This new method (at the time) of calibration overcame the difficulties of earlier strain gauge plethysmographs, especially those involving errors caused by lead-wire resistance, which in turn produced inaccurate blood flow recordings. Furthermore, the earlier plethysmographs required movement of the strain gauge for calibration, which produced calculation errors and associated temperature changes in the limb that was being moved. The contemporary plethysmographs are interfaced with computers, eliminating the need for strip-chart recordings and allowing the monitoring of blood flow directly from the computer screen.

Contrast-Water Therapy

An important finding of this study was the significant fluctuation of lower-leg blood flow during the 20-minute contrast condition. Contrast-water therapy with a 4:1 (warm to cold) ratio significantly increased blood flow in the lower leg as compared with the control condition. Interestingly, decreases in blood flow during the contrast treatment occurred during the change from warm to cold water. Increases in blood flow were also noted during the change back to warm from the cold immersion sequence, although this effect was reduced with successive immersions.

We suspect that the respective vasodilation and vasoconstriction of the peripheral blood vessels caused the significant differences between the 4 warm and cold transitions. However, because blood flow during the cold phases of the contrast therapy did not differ from that of control treatment, the vasoconstriction would appear to be a return to baseline only. If a significant decrease in blood flow occurred during the cold phases as compared with the control phase, suggesting a continued vasoconstriction, the "pumping theory" purported with contrast therapy would have been supported.

The fluctuations revealed in our study can be distinguished from the results of several previous studies.[4-6] From a methodologic standpoint, it is important to note that these particular studies measured intramuscular temperature by using indwelling temperature probes and did not concern themselves with blood flow measurements. Their results indicated that no significant fluctuations in intramuscular temperature occur during contrast therapy. They went on to further extrapolate that if there were no fluctuations in intramuscular temperature, it was unlikely that there would be significant fluctuations in intramuscular blood flow.[4-6] The results of our study may be compared with those from an outdated study by Woodmansey et al[22] that revealed fluctuations in skin temperature with a 6:4 (warm to cold) minute ratio. In this study, various warm to cold ratios were used to detect changes in forearm skin temperature as measured by an electric skin thermometer. Significant fluctuations occurred using the warm to cold ratios of 5:5, 6:4, and 7:3 minutes.[22] Our study revealed that a 4:1 (warm to cold) minute ratio is sufficient enough to produce fluctuations in blood flow. However, it is possible that the fluctuations noted in blood flow were because of changes in cutaneous circulation and not intramuscular circulation. Myrer et al[6] reported significant fluctuations in subcutaneous temperatures during contrast therapy using a hot to cold ratio of 1:1. They suggested that this was caused by changes in the peripheral circulation of the skin. Given the fact that the cold phase of the contrast therapy was only 1 minute long, it is likely that intramuscular temperatures were not affected. Thus, it is doubtful that the changes in blood flow occurred intramuscularly. Perhaps this is what Woodmansey et al[22] meant when they stated that the effects sought from contrast therapy is the active exercise of the *peripheral* vessels.

With regard to the pumping theory associated with contrast therapy, it may be necessary to point out some important considerations. Temperature-related constriction and dilation of the blood vessels is caused by contraction and relaxation of the muscular layer in the vessel wall. Our results suggest peripheral changes in circulation and not deep tissue changes. Furthermore, it must be noted that lymphatic vessels do not have a muscular layer in their walls so they do not appear to constrict or dilate, nor do they have valves to prevent backflow. Additionally, because the vascular system is a closed system,

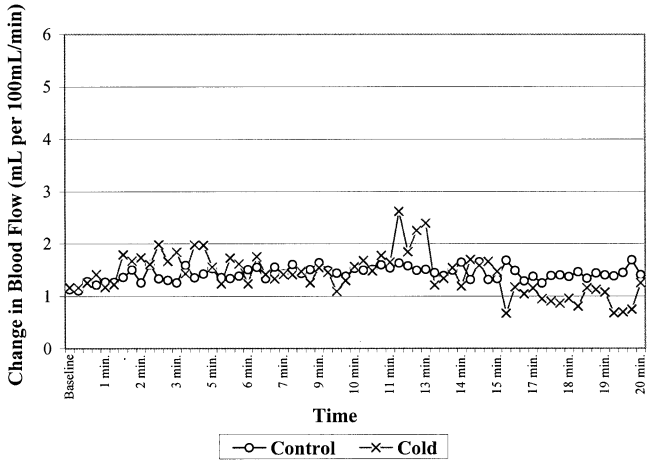

Fig 8. Change in blood flow between the control and cold conditions. Note that baseline indicates the point when blood flow measurements began.

edema cannot readily enter or be easily removed. We would suggest that the edema is removed almost entirely by the lymphatic system and does so without any "pumping" enhancement as has been supported experimentally and suggested both anatomically and physiologically.

Warm-Water Therapy

Blood flow increased from baseline as the warm treatment progressed. This increase in blood flow throughout the treatment was similar to the increases reported in studies examining forearm blood flow by Barcroft and Edholm,[9,10] although not quite as drastic as the 250% change that they report. We believe that immersion of the lower leg into 40°C water from the room temperature (22°C) environment caused the blood vessels to dilate, thus increasing blood flow to the area. The initial reaction of the blood vessels from baseline to 4 minutes and 30 seconds showed the greatest increase in percentage change in blood flow. However, from 4 minutes and 45 seconds until the 10th minute, the increase in blood flow was not as extreme. This likely is a result of the body becoming accustomed to the warm-water medium as the temperature gradient between the skin and the water decreased. After the first 10 minutes and 15 seconds of the treatment, the percentage change in blood flow again increased and remained consistently elevated throughout the duration of the 20-minute treatment. The steady increase in blood flow throughout the last 10 minutes of treatment may be due in part to the normal vasodilation of the blood vessels caused by the warm water.

Cold-Water Therapy

Submersion of the lower leg in 13°C water did not decrease blood flow in the midcalf region as compared with local blood flow during the control treatment. No significant differences in blood flow were observed across the time points measured during the cold treatment condition, except for some transient fluctuations. These deviations were caused by the divergence of only 1 subject. This subject had fluctuations throughout the entire cold treatment that influenced the mean value of all 24 subjects at this particular time point. We propose that the lack of change in blood flow, as compared with the control condition, may have been caused by a reaction of the body to preserve the core temperature or a vasomotor response (dilation) of the vessels. Clarke et al,[11] in their study examining the effects of different water temperatures on forearm blood flow, revealed that blood flow dropped with decreasing temperature, but once the water temperature fell below 14°C, blood flow increased and began to return to baseline. Therefore, the temperature of the water (13°C) in our study may have contributed to the lack of response in blood flow that we reported. Interestingly, one might suspect that moving the limb (brief period of muscle contraction) from the baseline position of rest into the cold-water immersion position might cause a fluctuation in blood flow. This was not the case during either the cold or control condition and was only observed during the 2 conditions involving warm (contrast and warm) water, thus leading us to believe that the initial fluctuation in blood flow was temperature related and not due to muscle movement.

There was a slight decrease in blood flow toward the end of the cold treatment. Although this was not statistically significant, it may suggest that if the treatment was continued beyond 20 minutes, a significant decrease in blood flow may have occurred. It is also possible that if colder water (<13°C) had been used during treatment, a decrease in blood flow would have been observed sooner. We purposely used water that was cooled to the same temperature (13°C) as our "contrast" cold immersion versus using other colder water. Interestingly, the "cold" whirlpool temperatures in 2 previous studies examining temperature changes with contrast therapy were set at 15.6°C.[4,5] Thus, further research is needed to determine the ideal temperature for cold-water immersion treatments.

Additionally, we hypothesize that submersion of the lower leg in cold water did not decrease blood flow because of the effects of gravity on extremity volume. When an extremity is placed in a dependent position, as was the case with the subjects in our study (seated in the whirlpool chair), the hydrostatic pressure within the blood vessel increases. This increase in hydrostatic pressure causes fluids to be forced into the tissues, thus increasing volume.[23,24] We were unable to assess this change because our subjects were already in the dependent position when baseline measurements were taken. However, a study by McCulloch and Boyd[25] revealed that a lower extremity placed in the dependent position will have an increased volume when compared with a lower extremity measured in a supine position. Perhaps, the increase in volume from gravity may have negated the decrease in blood flow from the cold-water therapy and caused the results to be similar to that of the control treatment. It would seem more practical, then, to use cold pack therapy in an elevated position, instead of cold tap water therapy on the lower leg if the desired effects are to decrease blood flow.

Limitations

We would like to point out the following limitations in our study. First, our results are limited to contrast protocols involving a 4 (hot) to 1 (cold) ratio. Second, the selection of healthy, sedentary male subjects was useful in controlling for confounding variables; however, it is not necessarily representative of a typical sports medicine clinic population (active and injured). Third, it is difficult for us to compare the results of our studies with those that have measured deep tissue temperatures. Fourth, the results of the study are limited to arterial blood flow (change in limb volume) and not venous outflow. This is important to note because the theory behind contrast "pumping" is based on venous outflow. Fifth, we did not use cold-water temperatures as low as might be recommended for other uses of cold-water immersion.[26] Although the optimal temperature for ice immersion is unknown, some clinicians advocate use of a water temperature between 2° and 4°C to bring about a quicker and more complete hypalgesia.[26]

CONCLUSIONS

This study has revealed that contrast-water therapy produces significant fluctuations in blood flow during a 20-minute treatment. This is valuable information because it was commonly thought that physiologic changes from warm- and cold-water therapy were not excessive enough to produce these peripheral fluctuations. We suggest that further studies involving contrast therapy to the lower leg in injured populations be carried out to determine whether our initial findings are clinically relevant. This is especially important if the clinical goals are to stimulate circulation within the lower leg, improve range of motion, and promote healing.

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